U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-257 456

Direct Environmental Factors at Municipal Wastewater Treatment Works

Camp, Dresser and McKee, Inc.

Prepared for

Environmental Protection Agency, Washington, D.C. Municipal Construction Div.

Jan 76

BEST SELLERS NTIS

FROM NATIONAL TECHNICAL INFORMATION SERVICE

Solar Heating and Cooling in Buildings: Methods of Economic Evaluation
COM–75–11070/PAT 48 p PC$4.00/MF$2.25

Design and Construction of a Residential Solar Heating and Cooling System
PB–237 042/PAT 233 p PC$8.00/MF$2.25

Performance of a Residential Solar Heating and Cooling System
PB–244 644/PAT 62 p PC$4.50/MF$2.25

Solar Energy
AD–778 846/PAT 478 p PC$12.50/MF$2.25

Stimulation of Geothermal Energy Resources
ERDA–37/PAT 52 p PC$4.50/MF$2.25

An Assessment of Industrial Energy Options Based on Coal and Nuclear Systems
ORNL–4995/PAT 329 p PC$10.00/MF$2.25

Environmental Impact Statements: A Handbook for Writers and Reviewers
PB–226 276/PAT 207 p PC$7.75/MF$2.25

Environmental Protection Guidelines for Construction Contract Specification Writers
ADA–014146/PAT 124 p PC$5.50/MF$2.25

A Review and Analysis of Environmental Impact Assessment Methodologies
ADA–013 359/PAT 21 p PC$3.50/MF$2.25

Procedures for Reviewing Environmental Impact Assessments and Statements for Construction Projects
ADA–015 020/PAT 25 p PC$3.50/MF$2.25

Computers in the 1980's: Trends in Hardware Technology
AD–783 323/PAT 20 p PC$3.50/MF$2.25

Minicomputers: A Review of Current Technology, Systems, and Applications
AD–783 316/PAT 104 p PC$5.50/MF$2.25

Microprocessor/Microcomputer Software Systems: Present and Future
ADA–013 322/PAT 25 p PC$3.50/MF$2.25

An Air Force Guide to Contracting for Software Acquisition
ADA–020 444/PAT 45 p PC$4.00/MF$2.25

A Dictionary for Unit Conversion
PB–249 659/PAT 456 p PC$17.50/MF Not Available

HOW TO ORDER

When you indicate the method of payment, please note if a purchase order is not accompanied by payment, you will be billed an addition $5.00 *ship and bill* charge. And please include the card expiration date when using American Express.

Normal delivery time takes three to five weeks. It is vital that you order by number or your order will be manually filled, insuring a delay. You can opt for *airmail delivery* for a $2.00 charge per item. Just check the *Airmail Service* box. If you're really pressed for time, call the NTIS Rush Order Service. (703) 557-4700. For a $10.00 charge per item, your order will be airmailed within 48 hours. Or, you can pick up your order in the Washington Information Center & Bookstore or at our Springfield Operations Center within 24 hours for a $6.00 per item charge.

You may also place your order by telephone or TELEX. The order desk number is (703) 557-4650 and the TELEX number is 89-9405.

Whenever a foreign sales price is NOT specified in the listings, all foreign buyers must add the following charges to each order: $2.50 for each paper copy; $1.50 for each microfiche; and $10.00 for each Published Search.

Thank you for your interest in NTIS. We appreciate your order.

METHOD OF PAYMENT

☐ Charge my NTIS deposit account no.________

☐ Purchase order no.________

☐ Check enclosed for $________

☐ Charge to my American Express Card account number

Card expiration date________

Signature________

☐ Airmail Services requested

NAME________

ADDRESS________

CITY, STATE, ZIP________

Clip and mail to:

NTIS
National Technical Information Service
U.S. DEPARTMENT OF COMMERCE
Springfield, Va. 22161
(703) 557-4650 TELEX 89-9405

Item Number	Quantity		Unit Price*	Total Price*
	Paper Copy (PC)	Microfiche (MF)		

* All Prices Subject to Change

10/76

Sub Total	
Additional Charge	
Enter Grand Total	

265086

PB 257 456

EPA-430/9-76-003

TECHNICAL REPORT

DIRECT ENVIRONMENTAL FACTORS AT MUNICIPAL WASTEWATER TREATMENT WORKS

Evaluation and Control of Site Aesthetics, Air Pollutants, Noise and Other Operation and Construction Factors

January 1976

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Water Program Operations
Washington, D.C. 20460

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

MCD—20

114

EPA REVIEW NOTICE

This report has been reviewed by the Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

Please indicate the title of the publication and the MCD number.

BIBLIOGRAPHIC DATA SHEET

1. Report No. EPA 430/9-76-003 MCD-20

2.

3. Recipient's Accession No.

4. Title and Subtitle
Direct Environmental Factors at Municipal Wastewater Treatment Works: Evaluation and Control of Site Aesthetics, Air Pollutants, Noise and Other Operation and Construction Factors

5. Report Date
January 1976

6.

7. Author(s)
R. Ernest Leffel

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Same as Box 12

10. Project/Task/Work Unit No.

11. Contract/Grant No.
68-01-0324

12. Sponsoring Organization Name and Address
EPA
Office of Water Program Operations
401 M Street SW
Washington, D.C. 20460

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstracts

The purpose of this report is to provide the methodology and reference information for federal guidelines and the designers of publicly owned wastewater treatment works in compliance with the Federal Water Pollution Control Act Amendment of 1972 (P.L. 92-500). To assist in obtaining maximum flexibility and economy in the design, construction, operation, and maintenance of wastewater treatment works, while ensuring the required level of environmental compatibility, relevant considerations are presented. Municipal wastewater treatment works include treatment plants, pumping stations, separation structures, interceptors, force mains, certain collection systems, and outfalls.

17. Key Words and Document Analysis. 17a. Descriptors

Wastewater Treatment Works
Evaluation of Site Aesthetics
Control of Site Aesthetics

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group

PRICES SUBJECT TO CHANGE

18. Availability Statement

19. Security Class (This Report)
UNCLASSIFIED

20. Security Class (This Page)
UNCLASSIFIED

21. No. of Pages
114

22. Price
$5.50 - 2.25

FORM NTIS-35 (REV. 3-72)

USCOMM-DC 14952-P72

EPA-430/9-76-003

TECHNICAL REPORT

DIRECT ENVIRONMENTAL FACTORS AT MUNICIPAL WASTEWATER TREATMENT WORKS

Evaluation and Control of Site Aesthetics, Air Pollutants, Noise and Other Operation and Construction Factors

By

R. Ernest Leffel
Contract No. 68-01-0324

January 1976

Prepared For
Environmental Protection Agency
Office of Water Program Operations
Washington, D.C. 20460

ia

MCD—20

PREFACE

With the impetus given to water quality improvement under PL 92–500 through the municipal construction grants program, the design and construction of many new wastewater treatment plants have commenced. At the same time, the public has become accustomed to better environmental planning of such structures. In the past, environmental factors have created public doubts and uneasiness about nearby municipal treatment works. These adverse environmental factors can and must be prevented or controlled, to minimize objection to wastewater treatment works in the neighborhood.

This report, although not EPA policy, does contain a good summary of evaluation and control measures designed to arrive at environmentally sound projects. Environmental factors considered in the report include odors, noise, site planning, architecture, lighting, aesthetics, subsurface conditions, construction nuisances, and treatment during construction.

Designers and review authorities must exert special effort to ensure projects are environmentally sound. In a few cases, this may result in higher capital and operating costs. Generally, however, costs are lower over the planning period because there is no need for expensive alterations to correct nuisance problems. The Cost-Effectiveness Analysis Guidelines (40 CFR 35, Appendix A, *Federal Register*, September 10, 1973) details how to incorporate non-monetary factors, such as social and environmental factors, into cost-effectiveness analysis.

The level of detail required in a facility plan to deal with direct environmental effects will vary according to the circumstances, and the size, nature, and location of the undertaking. Local municipalities and consultants should discuss the extent of planning required with officials of the State and EPA.

TABLE OF CONTENTS

Chapter Page No.

1 INTRODUCTION 1
1.1 Purpose of Publication 1
1.2 Goals 1
1.3 Scope 2
1.4 Reference Legislation 2
1.5 Related EPA Publications 2

2 PLANNING AND SITE DESIGN 3
2.1 Planning Studies and Investigations 3
2.2 Site Design 5
2.2.1 Introduction 5
2.2.2 General Considerations 6
2.2.3 Site Design Examples 7
2.3 Specific Site Design Considerations 14
2.3.1 Process Construction Considerations Affecting Site Development 14
2.3.2 Building Orientation 16
2.3.3 Shoreline and Wetlands Planning 16
2.3.4 Flood Plain Avoidance 19
2.3.5 Recreation and Education 19
2.3.6 Wildlife Habitats and Historic Sites 19
2.3.7 Landscaping 20
2.3.8 Lighting 20
2.3.9 Security 21
2.3.10 Building Aesthetics 21
2.3.11 Future Development 21
2.3.12 Site Traffic 22

3 AIRBORNE POLLUTANTS 23
3.1 General Information 23
3.2 Odors 24
3.2.1 Units of Expression 24

TABLE OF CONTENTS (Continued)

Chapter | Page No.

3.2.2 Odor Potential at Wastewater Treatment Facilities 25
3.2.3 Characteristics of Odors 26
3.2.4 Hydrogen Sulfide 27
3.2.5 Standards or Acceptable Levels 29
3.2.6 Odor Detection and Measurement 30
3.2.7 Odor Analysis Methodology 31
3.2.8 Odor Control Measures 31
3.2.9 Odor Intensity Determinations 37
3.2.10 Sample Calculations 38
3.3 Aerosols and Particulates 45
3.4 Gases 47
3.5 References 48

4 NOISE 53
4.1 General Background 53
4.2 Units of Expression and Measurement 54
4.3 Typical Noise Levels 57
4.4 Acceptable and Standard Noise Levels 57
4.4.1 Allowable Exposure to Impact or Impulsive Noise 57
4.4.2 Impulse Noises 61
4.4.3 Community Noise Criteria 61
4.4.4 Machinery Noise 64
4.4.5 Interior Noise 64
4.4.6 Exterior Noise 64
4.5 Noise Control Methods 66
4.5.1 Source Control 66
4.5.2 Piping Systems 66
4.5.3 Mechanical Aerators 67
4.5.4 Compressors, Fans, and Blowers 67
4.5.5 Vacuum Filter Pumps and Blowers 67
4.5.6 Pumps 67
4.5.7 Incinerators 67
4.5.8 HVAC 67
4.5.9 Architectural Noise Control 67
4.5.10 Construction Noise Control 68
4.5.11 Operational Noise Control 70
4.6 Acoustical Computations 70
4.6.1 Addition of Decibels 71
4.6.2 Sound Power Level/Pressure Level Conversions 71
4.6.3 Reduction of Sound Pressure Level With Distance Outdoors 73

TABLE OF CONTENTS (Continued)

Chapter Page No.

4.6.4 Conversion of Octave Band Sound Pressure Levels to A-Scale Sound Pressure Levels 74
4.6.5 Calculation of Effective Sound Isolation of Composite Barrier Construction 74
4.6.6 Calculation of Sound Insulation From an Enclosed Room to Outside 80
4.6.7 Calculation of Noise Output From Plant Equipment 81
4.6.8 Calculation of Total Noise Levels at Typical Locations on Periphery of Wastewater Treatment Works Property From All Significant Sources 82
4.7 References 87

5 SITE PREPARATION, CONSTRUCTION, AND OPERATION PROBLEMS 89
5.1 Flooding and Drainage 89
5.2 Site Preparation 90
5.3 Disposal of Clearing Debris and Construction Wastes 91
5.4 Excavation and Backfill 92
5.5 Pile Driving, Blasting, and Earthquake Problems 93
5.6 Dredging 93
5.7 Erosion and Siltation 94
5.8 Restoration of Easements After Construction 97
5.9 Wastewater Treatment During Treatment Plant Modification 98
5.10 Sludge, Process Sidestreams, and Onsite Disposal 99
5.11 Groundwater Pollution 100
5.12 References 101

Appendix A Reference Legislation 103

LIST OF FIGURES

Fig. No. Page No.

2-1 Wastewater Treatment Works Formulation and Development 4
2-2 Urban Site 8
2-3 Socially Sensitive Suburban Site 10
2-4 Ecologically Sensitive Suburban Site 12
2-5 Shoreline Planning 17
3-1 Gaussian Distributions 39
3-2 Gaussian Distribution Curve 39
3-3 Ordinate Values of the Gaussian Distribution 40
3-4 Area Under Gaussian Distribution Curve 40
3-5 Horizontal Dispersion Coefficients 41
3-6 Vertical Dispersion Coefficients 42
3-7 The Product of $\sigma_y \sigma_z$ 44
4-1 Frequency-Response Characteristics 56
4-2 Peak Permissible Sound Pressure Levels 63
4-3 Construction Equipment Noise Ranges 65
4-4 Sound Level Conversion Chart 76
4-5 Effective Transmission Loss of Composite Acoustic Barriers 77
4-6 Transmission of Noise Through Walls and Floors 78
4-7 Environmental Noise Levels for Residential, Hospital, and Educational Activity 83
4-8 Plan for Example 4-6 84

LIST OF TABLES

Table No. Page No.

3-1 Odorous Vapors Found at Wastewater Facilities 28

3-2 Possible Odor Prevention and Control Methods 36

3-3 Key to Stability Categories 37

4-1 Equivalent Sound Levels 58

4-2 Estimated Percentage of Urban Population Residing in Areas With Various Day/Night Noise Levels 58

4-3 Average Single Number Sound Levels 59

4-4 Yearly Average Equivalent Sound Levels Identified as Requisite To Protect Public Health and Welfare With Adequate Margin of Safety 60

4-5 Typical Values of Peak Sound Pressure Levels for Impulse Noise 62

4-6 Noise Exposure Levels 62

4-7 Basic Information on Construction Equipment 69

4-8 Addition of Decibels 72

4-9 C Values for Omnidirectional Noise Sources 72

4-10 Relation Between Octave Band Center Frequency and A-Scale Frequency 75

4-11 Airborne Sound Transmission Loss Values for Some Common Building Constructions Derived From Field Measurements 79

1. INTRODUCTION

1.1 PURPOSE OF PUBLICATION

The purpose of this report is to provide the methodology and reference information for federal guidelines and for designers of publicly owned wastewater treatment works. To assist in obtaining maximum flexibility and economy in the design, construction, operation, and maintenance of wastewater treatment works, while ensuring the required level of environmental compatibility, relevant considerations are presented. Wastewater treatment works include treatment plants, pumping stations, separation structures, interceptors, force mains, certain collection systems, and outfalls.

1.2 GOALS

Wastewater treatment works must not be the *ugly duckling* in the community but rather the *good neighbor*. In the past, odors, unsightliness, dust, and erosion have created public doubts and uneasiness about nearby municipal treatment works. These adverse environmental factors can and must be prevented or controlled, to minimize objections to wastewater treatment works in the neighborhood. In the final analysis, the design engineer must ask: "Would I be willing to live near this plant?" It is *not* acceptable to create new environmental problems while solving water quality problems.

Incorporation of environmental considerations in the design, construction, operation, and maintenance of wastewater treatment works should ultimately result in the least cost to the total fiscal and environmental resources. Capital and operating dollar costs may not be lower, but such considerations of natural environmental resources should lead to overall savings in total resources. Works that are designed, constructed, and operated with consideration of the social and ecological aspects of the environment can both encourage and facilitate the development and improvement of nearby lands in conformity with comprehensive plans for the area.

In assessing impacts on an environmental factor, the design engineer must (a) check whether the impacted environmental factor is important and (b) determine whether the effects on the environmental factor are significant. Detailed assessments should be largely confined to important factors which might be significantly affected by a plan of action.

1.3 SCOPE

It is recognized that there are many broader issues relating to the overall environmental impacts of wastewater treatment works. Although this document is concerned mostly with direct environmental factors, some of the broader environmental issues are identified, together with references where additional information may be found.

The environmental compatibility considerations discussed in this report are limited to those direct factors affected by the design, construction, operation, and maintenance of wastewater treatment works. Possibly significant effects, both beneficial and adverse, of the works on each aspect of the environment should be evaluated in the project conception stage and in the facilities planning stage (when a formal assessment is required) and reevaluated in the design stage, always keeping in mind the possible impact caused by construction of the works and by the operation and maintenance of the completed works.

The Environmental Protection Agency (EPA) requires that assessments of the possible impacts on significant aspects of the environment accompany all plans for wastewater treatment works submitted to the EPA for federal assistance.

1.4 REFERENCE LEGISLATION

Legislation with respect to environmental factors at wastewater treatment works is discussed in Appendix A.

1.5 RELATED EPA PUBLICATIONS

1. Federal Water Pollution Control Act Amendments of 1972.(P L 92-500).
2. *Design, Operation and Maintenance of Wastewater Treatment Facilities* (September 1970).
3. *Procedures for Providing Grants to State and Designated Areawide Planning Agencies* (40 CFR Subchapter B. Part 35, November 28, 1975).
4. *Policies and Procedures for the State Continuing Planning Process* (40 CFR Part 130, November 28, 1975)
5. *Preparation of Water Quality Management Plans*(40 CFR Part 131,November 28, 1975).
6. *Preparation of Environmental Impact Statements* (40 CFR Part 1500, 1 August 1973).
7. *Preparation of Environmental Impact Statements* (40 CFR Part 6, April 14, 1975) .
8. *Areawide Waste Treatment Management Planning Areas and Responsible Planning Agencies* (38 CFR Part 103, 30 May 1973, and 38 CFR Part 126, 14 September 1973).
9. *Cost-Effectiveness Analysis Guidelines* (40 CFR Part 35, 10 September 1973).
10. *Guidance for Preparing a Facility Plan* (U.S. EPA, May 1975).

2. PLANNING AND SITE DESIGN

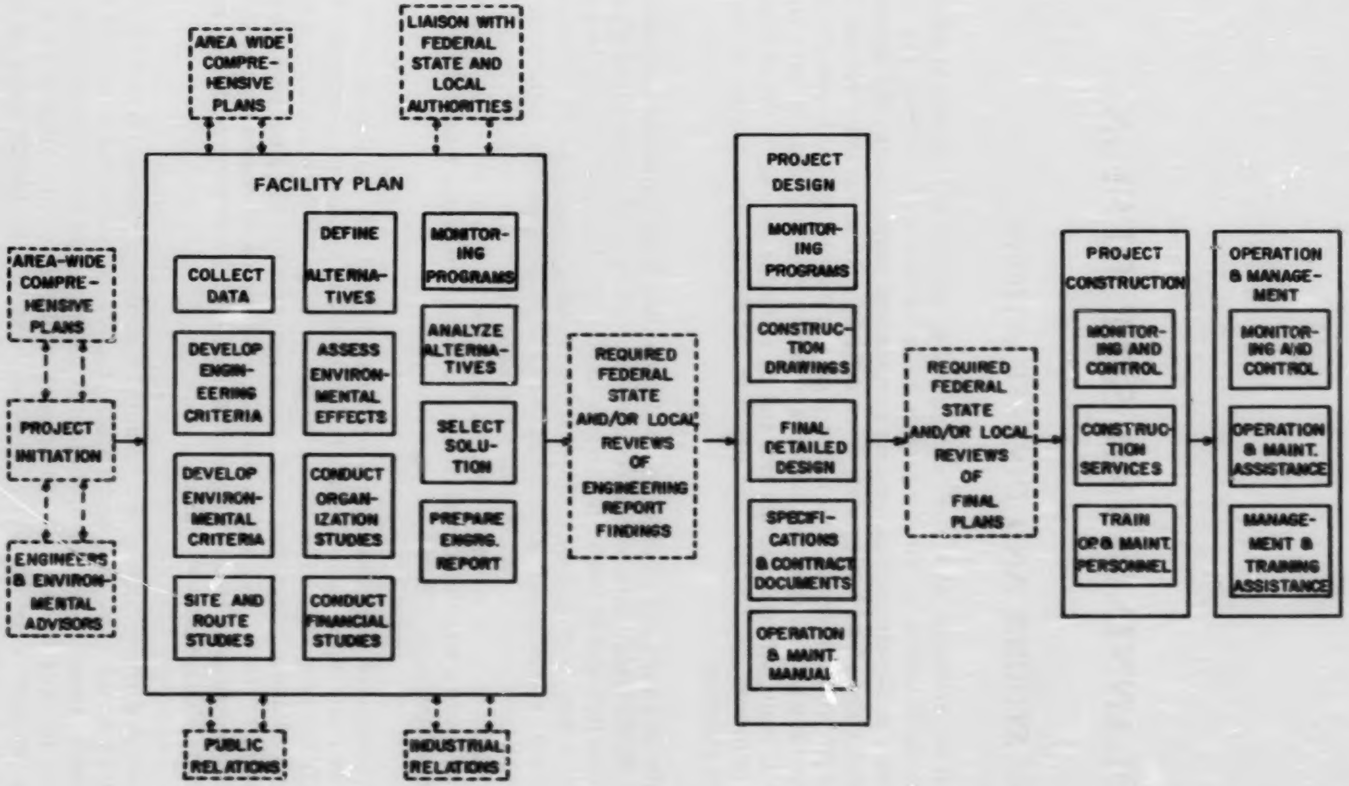
2.1 PLANNING STUDIES AND INVESTIGATIONS

The engineer should be concerned with minimizing possibly adverse environmental effects, and maximizing beneficial effects, of the wastewater works project on the region. Fig. 2-1 illustrates general items in the life cycle of wastewater treatment works. During the formulation and development stage of such a project, there must be a close relation between the design engineer and government, public, and industry representatives. Areawide comprehensive plans, with criteria and guidelines for wastewater works planning, should have been prepared by regional, basin, and state authorities and be available for use by the engineer. The reader is referred to sections 201, 208, and 303 of PL 92-500 for more detailed information on such facilities planning.

Much of the difficulty in locating wastewater works has resulted from inadequate consideration of aesthetics in the design, construction, and operation of these works. Odors and noises, although not dangerous to health or safety, can be very unpleasant. Intrusive or badly focused light fixtures can be a source of irritation. Unattractive buildings and grounds can create adverse public reactions, as can poorly maintained works. The designer and operator must reduce these disturbing conditions, if not eliminate them entirely. In the past, the possibility of gas explosions, exposure to wastewater from ruptured tanks, overflows of wastewater, chlorine and oxygen hazards, and the danger of open tanks or ponds has biased the public against siting these facilities near a developed community.

Other factors to be considered in evaluating environmental impact are: the degree to which short-term uses can be made of the environment while maintaining its long-term productivity; the period for which the proposed works should be designed, to handle wastewater needs effectively; the beneficial and adverse effects on land development in the area, both within and without the treatment works; and any irreversible modification of resources caused by the proposed project, including utilization of potentially valuable land, water resources, and possible depreciation of adjacent property values.

Because of the increasing complexity of the planning and design process, based on the necessity of considering social, ecological, and aesthetic factors (as well as the more conventional engineering requirements), government authorities should obtain the advice of qualified public representatives in those areas in which the public will be directly affected, such as initial site selection, environmental inventory, planning, and review. Identification of the effects (both monetary and resource) on the environment in terms which the public can


AREA WIDE COMPRE-HENSIVE PLANS
LIAISON WITH FEDERAL STATE AND LOCAL AUTHORITIES
AREA-WIDE COMPRE-HENSIVE PLANS
PROJECT INITIATION
ENGINEERS & ENVIRON-MENTAL ADVISORS
FACILITY PLAN
COLLECT DATA
DEFINE ALTERNA-TIVES
MONITOR-ING PROGRAMS
DEVELOP ENGIN-EERING CRITERIA
ASSESS ENVIRON-MENTAL EFFECTS
ANALYZE ALTERNA-TIVES
DEVELOP ENVIRON-MENTAL CRITERIA
CONDUCT ORGAN-IZATION STUDIES
SELECT SOLU-TION
PREPARE ENGRG. REPORT
SITE AND ROUTE STUDIES
CONDUCT FINANCIAL STUDIES
PUBLIC RELATIONS
INDUSTRIAL RELATIONS
REQUIRED FEDERAL STATE AND/OR LOCAL REVIEWS OF ENGINEERING REPORT FINDINGS
PROJECT DESIGN
MONITOR-ING PROGRAMS
CONSTRUC-TION DRAWINGS
FINAL DETAILED DESIGN
SPECIFI-CATIONS & CONTRACT DOCUMENTS
OPERATION & MAINT. MANUAL
REQUIRED FEDERAL STATE AND/OR LOCAL REVIEWS OF FINAL PLANS
PROJECT CONSTRUCTION
MONITOR-ING AND CONTROL
CONSTRUC-TION SERVICES
TRAIN OP& MAINT. PERSONNEL
OPERATION & MANAGE-MENT
MONITOR-ING AND CONTROL
OPERATION & MAINT. ASSISTANCE
MANAGE-MENT & TRAINING ASSISTANCE

NOTE: ITEMS WITHIN SOLID LINES ARE IMPLEMENTED BY THE ENGINEER.

FIG. 2-1. WASTEWATER TREATMENT WORKS FORMULATION AND DEVELOPMENT

comprehend and evaluate will result in valid reactions to the proposals and will improve the probability of the project's success.

The planning process should start with an environmental survey of the site, adjacent lands, municipality, and region, to identify those factors which could be important in preventing or minimizing significant adverse effects. The engineer may require the assistance of professionals in one or more of the environmental disciplines, to provide expert advice about the importance of specific site characteristics.

Once the survey is completed, permissible levels or amounts of aerosols, odors, noise, lighting, or other possible problems resulting from wastewater works can be determined for that particular area. Land use, environmental, and wastewater design requirements can then be integrated, and possible alternatives investigated for feasibility. Finally, an environmentally compatible solution can be recommended, after a detailed engineering study of the feasible alternatives.

With regard to the effects of the proposed works on the environment, the planning phase should also include an evaluation of the possible effects during each step of the proposed project, such as:

1. the effect of preempting land for the works
2. the effect of effluent discharges
3. the effect of possible diversion of existing wastewater flow
4. the effect of flooding, plant malfunctions, and emergency situations
5. the effect of proposed sludge treatment and disposal
6. the possible effect of noise, aerosols, and odors
7. the effects of construction, operation, and maintenance of the facilities.

Appendix A provides a useful reference for Federal laws and executive orders which should be considered in the planning phase.

2.2 SITE DESIGN

2.2.1 Introduction

Selection of the wastewater treatment facility site should be based on careful consideration of the region's land use and development patterns, as well as engineering constraints of the existing and proposed wastewater system. Site selection is covered in other EPA documents; however, the basic principles of site analysis and design described here can be used to make a general assessment of site suitability.

Because municipal wastewater treatment facilities are the end points of sewer systems, they are generally located at a lower elevation and near a body of water, or irrigable land, capable of accepting their treated effluent.

Unfortunately, it is usually in those areas where a facility is most needed that its site is most likely to be subject to the constraints of neighboring development. It is a consequence of urban geography, politics, and economics that, as an area's development necessitates the building of a wastewater treatment facility, this same development more severely restricts the design of the site. This chapter will address how the nature of these constraints can be discovered and addressed in site planning and design.

The designer should become familiar with the proposed site and its neighborhood. Because a wastewater facility is an essential social service, its design should maximize its contribution to the area's social resources and minimize any detrimental effects. The wastewater facility must be well engineered, but onsite planning and development which improve the facility's operation, aid its acceptance in the neighborhood, and minimize its effects on sensitive natural features are also required.

Characteristics of the site and its neighborhood must be inventoried, to identify any features which might make some aspect of site development incompatible with its environs. Factors influencing site design are both natural and social. For example, it would be important to know both that a specific section of the site is subject to spring flooding and that one of its borders is shared with a residential community. Both facts indicate that sections of the site should be avoided or be given special treatment. It cannot be emphasized too strongly that natural and social factors influence design. Obviously, an area subject to flooding requires special design treatment, if it must be used, to safeguard facility access and operation during flood. Similarly, a section close to relatively incompatible land use (such as residences) requires a special design effort and perhaps development expense to render the facility acceptable.

Matters to be investigated include, but are not limited to: topography, drainage, surface water, groundwater, soil types, bedrock, vegetation, prevailing winds, temperature ranges, precipitation, seasonal solar angles, wildlife habitats, ecosystems, regional and local land use, transportation, zoning, archaeological and historical features, and special natural features.

2.2.2 General Considerations

A successful wastewater facility site design makes use of the existing and developed features of the site to satisfy the demands of the treatment facility and its neighbors and to minimize any conflict of interest. It is the designer's responsibility to take the information gathered in the site inventory, together with the requirements of process and plant operation, and produce a site and facility layout satisfactory to all parties. Design is not the simple result of analysis of site constraints. Assessment of the site's character does not establish what should be done but only what would be affected if something were done. The designer must clarify goals for the site design, to facilitate public decisions as to which site features are to be respected, enhanced, altered, or destroyed in pursuit of those goals.

Specific principles to be followed in the design of wastewater facilities are given in a later section of this chapter. Before reviewing such matters, three examples of site inventory and design will be discussed, to illustrate how site constraint and assessment information may be gathered and how it informs and influences, but does not dictate, site design decisions. From the examples, three basic strategies for site planning and design can be abstracted: (a) advantageous use of existing site conditions to solve problems of facility functioning and environmental compatibility, (b) disposition and design of the necessary facility elements to minimize or avoid environmental compatibility problems, and (c) addition of design elements not necessary to facility function to solve environmental compatibility problems. The choice and mix of strategies to solve site design problems will depend on the particular problems of each site and the skills of the designers. A fourth strategy not discussed here (because it is more closely related to process engineering than site analysis) is studying feasible alternative treatment processes to select the one best suited to achieve both the required effluent quality and environmental compatibility.

2.2.3 Site Design Examples

The following examples illustrate three cases in which site inventories were used to assist site design. These cases (one urban and two suburban semirural sites) show how principal environmental problems can change according to the site's location and character. In the urban area, the principal concerns are maintenance of limited urban recreational and open space and separation of the facility from its sensitive neighbors. In the suburban cases, the principal problems are siting the facility in a socially sensitive environment in one case and in an ecologically sensitive area in the other.

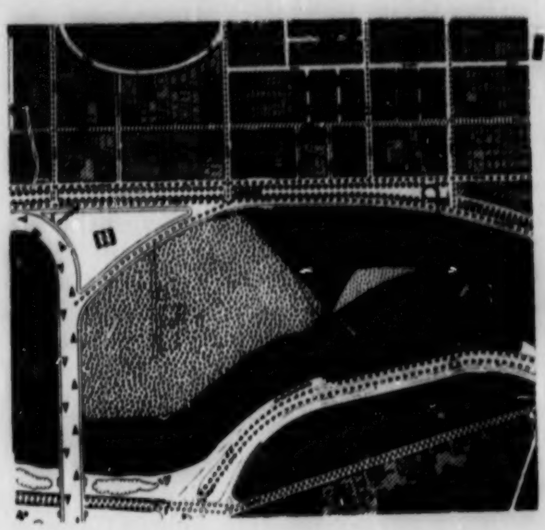
It must be remembered that these examples are meant only to be illustrative of the design process and are neither complete nor definitive.

Although the analyses and site planning drawings are reproduced here in black and white, they need not be executed monochromatically. The specific examples illustrate graphic techniques which would be useful for client presentation and indicate a rather high level of graphic competence. In this way public discussions and decisions concerning the treatment facility can benefit from the engineer's and designer's expertise.

The drawings and accompanying commentaries show how the inventory of existing site characteristics, design goals, and site design solutions can be documented. In the urban case, the inventory of existing conditions, design goals, and site design solutions are reduced to single drawings. The socially sensitive suburban case presents both initial and final site plans. The final example comprises six drawings presenting existing conditions, two of design choices, and one final site design.

URBAN SITE. In this hypothetical urban case, the inventory of existing conditions (Fig. 2-2a) illustrates existing land uses and traffic patterns. The site, located in a densely developed urban setting, also contains a large undeveloped open area. The inventory allows the designer to establish specific goals in the site development (Fig. 2-2b). Based on discussions between the engineer and client, it has been decided to (a) preserve the character of the park; (b) design the street edges to respond to the residential neighborhood, historical monument, and heavy traffic; (c) preserve the marsh as an ecologically important feature; and (d) maintain the river's edge for recreation. A location for vehicular access to the site and the general area for facility development have been found. The final site design (Fig. 2-2c) illustrates a layout responsive to the identified site planning goals. The facility has been developed away from the residential edge, and existing trees and new landscaping have been used as buffers. Because the facility has been located nearer the river, the use of the river's edge as a recreation area has been accomplished by building a garden walk and esplanade. On this tight urban site, the facility would have to be placed near either the residential front or the river. In either case, facility development would require special treatment of this narrow edge. Once the important design goals are established, the designer should consider all solutions

FIG. 2-2A.
EXISTING CONDITIONS



INVENTORY OF EXISTING CONDITIONS

LEGEND

■ RIVER—Sailing, fishing, limited sunbathing

▨ OPEN LAND—Several abandoned bldgs. and dump

■ PARK—Mature trees, some sitting areas

▨ MARSH—Used by water fowl in spring and fall

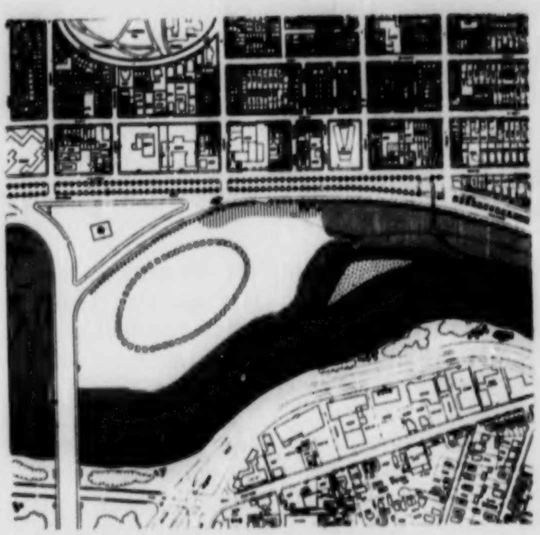
RESIDENTIAL
Single family
▪▪▪ Multi family
▬ High rise

PUBLIC BLDG.
■ Institutional
Educational

BUSINESS
■ Commercial
Light Industry

•••• Historically significant
— Views of site and from site
►► Heavy car and truck traffic
••• Heavy car traffic
···· Moderate car traffic
······ Light car traffic
— Pedestrian

FIG. 2-2B.
DESIGN GOALS



KEY SITE PLANNING FACTORS

LEGEND

■ Preserve and enhance character of park

▥ Design edge of street for residential neighborhood

▨ Preserve marsh

■ Design shoreline for river recreation

······ Design street edge for heavy traffic

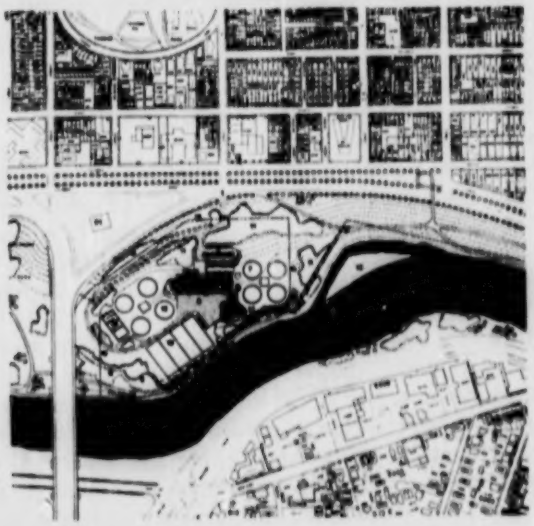
••••• Potential public access

♦ Most suitable vehicular access

• Respect historic site

▬ Approximate site of wastewater treatment plant

FIG. 2-2C.
SITE DESIGN SOLUTION



FINAL SITE PLAN

LEGEND

1. Site entry
2. Visitor and staff parking
3. Truck yard
4. Process building
5. Administration
6. Maintenance facilities
7. Primary sedimentation basin
8. Earth mound using materials from excavation
9. Gravity thickeners
10. Mechanical aeration basin
11. Landscape visual barrier
12. Final clarifiers
13. Chlorine contact tank
14. Bicycle and walking path
15. Marsh
16. Fence
17. Influent
18. Effluent
19. Mechanical bar screens
20. Aerated grit chambers
21. Memorial
22. Garden wall and esplanade seating

which meet the requirements, even if an additional design element is necessitated. In very tight urban sites, like this hypothetical one, such extra elements are to be expected as part of the development cost.

SOCIALLY SENSITIVE SUBURBAN SITE. The inventory of existing conditions for this suburban site (Fig. 2-3a and b) shows the site as a large undeveloped tract between two suburban streets lined with single-family houses. Fig. 2-3c indicates the prevailing winds and seasonal solar angles--general information which should be ascertained for any wastewater treatment facility. Prevailing wind information allows the designer to place odor and aerosol processes downwind of inhabited areas. Solar angles are used to design the facility buildings for minimum energy consumption for heating, ventilating, and air conditioning. Also, in northern climates, truck areas would be placed where snow melting could be aided by the sun.

For this particular case, the principal site constraint is the existence of residential neighbors. Development of the site must produce a socially acceptable facility within the heavily vegetated zone.

The design analysis (Fig. 2-3d) shows the wastewater treatment facility located in the center of the tract, with buffer zones between it and the residential areas. The specific area chosen for development is a relatively level sector above flood level. The designer has also combined site access with the influent line, so that minimal construction can be undertaken, with as little destruction of the existing vegetation as possible. The site design schematic (Fig. 2-3e) indicates the preliminary layout of process elements and buildings on the site. Truck and driving areas have been kept on the sunny side of major structures, to aid snow melting. Ample space for future process expansion is also indicated. The final site plan (Fig. 2-3f) shows the site and orientation of the initial construction. Also, the design intention of using vegetation as a visual buffer for the residential areas is emphasized by boundaries of vegetation around the facility.

In this case, site analysis and design have identified the major compatibility problem as that of screening the facility from visually sensitive neighbors. In this regard, the designer made use of the existing site vegetation and the site size and boundaries. In addition, the entry road is so located that truck and automobile traffic can be easily separated at the entrance to the plant.

ECOLOGICALLY SENSITIVE SUBURBAN SITE. In this hypothetical case, the very large parcel of land, somewhat haphazardly bounded, presents combined problems of incompatibility. The principal constraint is the serious ecological problem associated with development of the site. Extensive analyses of natural conditions in the area (shown in part in Fig. 2-4b, c, d, and e) indicated that most of the site would be unsuitable for development because of severe slopes, erodible soils, flood plain and drainage pattern encroachment, and sensitive vegetation. The first problem of site planning is thus finding an area of adequate size for development which is relatively insensitive ecologically. The second problem is that the site requires visual buffer planning, similar to the previous example.

Based on the site inventory (Fig. 2-4a through e), a parcel of land which would be safe for development—presenting no insuperable problems of erodible soils, flood plain encroachment, valuable vegetation, and special wildlife habitats—has been found. Fig. 2-4f shows this same parcel hidden from the view of most of the residential neighbors. The designer has thus managed to solve both problems by choosing the larger area. A site design drawing could be eliminated, because the principal and secondary design goals have been achieved.

FIG. 2-3A.
EXISTING
CONDITIONS—
TOPOGRAPHY

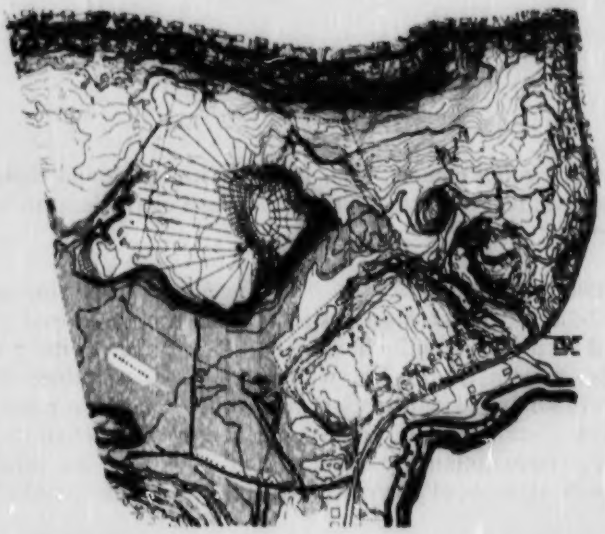


FIG. 2-3B.
EXISTING
CONDITIONS—
VEGETATION

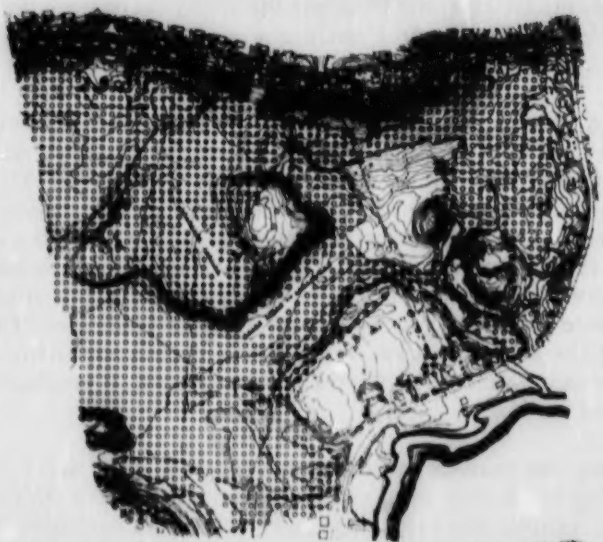


FIG. 2-3C.
EXISTING
CONDITIONS—
SOLAR ANGLES
AND WINDS

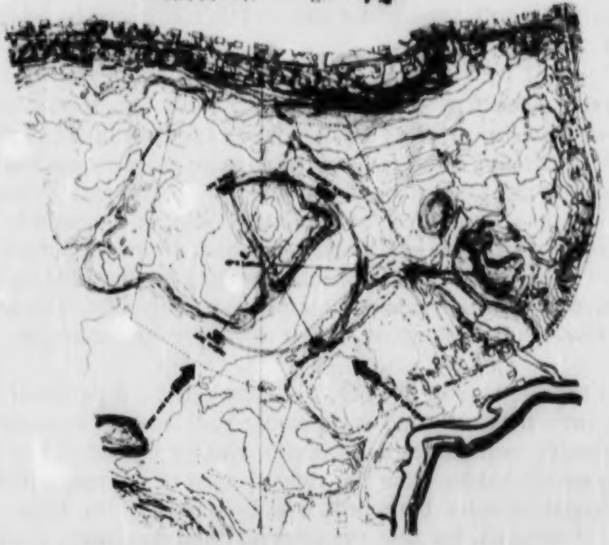


**FIG. 2-3D.
SITE FACTORS
ANALYSIS**

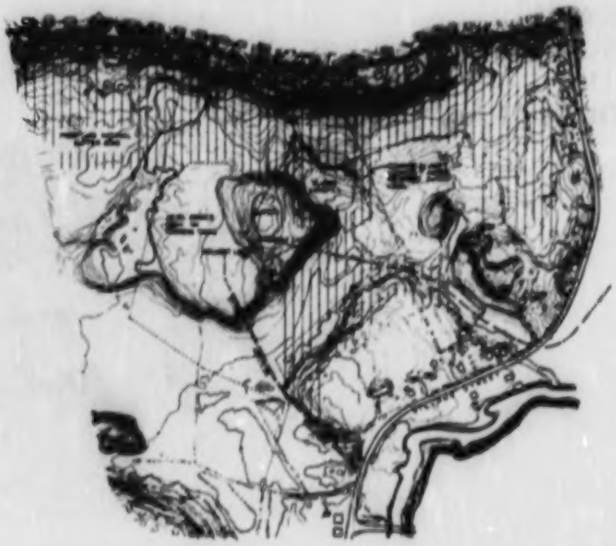


**FIG. 2-3E.
SITE DESIGN
SCHEMATIC**

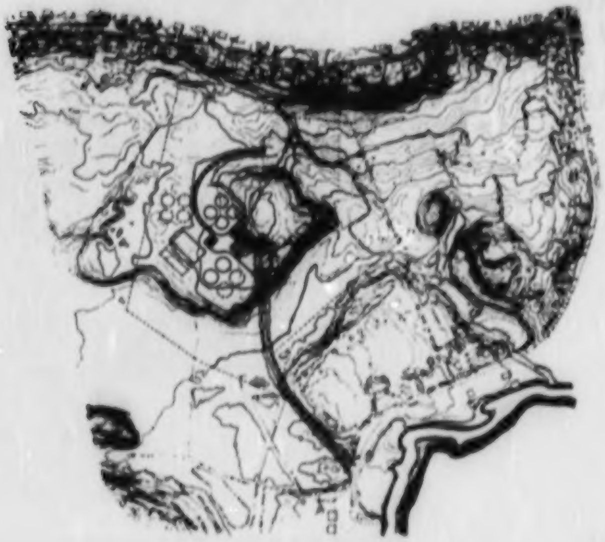


**FIG. 2-3F.
FINAL SITE PLAN**

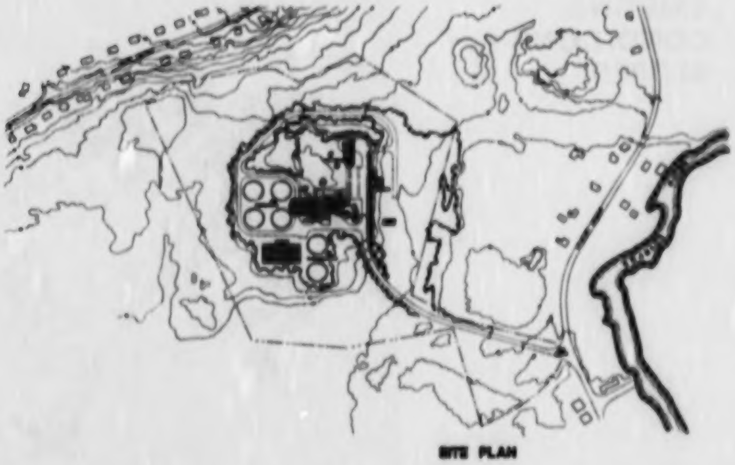


FIG. 2-4A.
EXISTING
CONDITIONS—
SITE BOUNDARIES

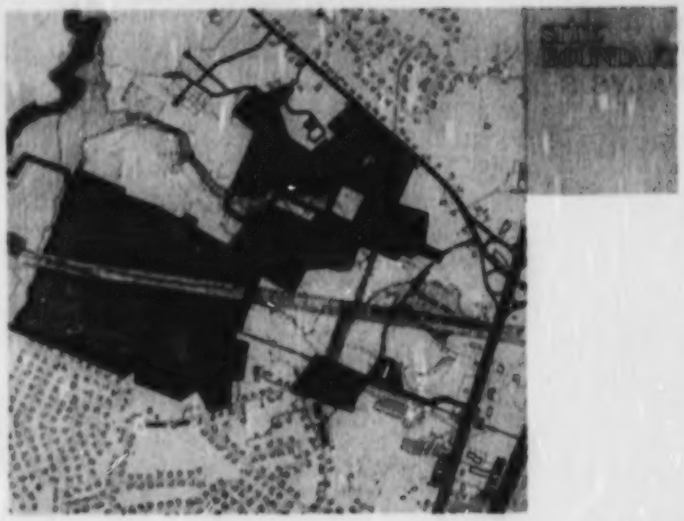

SITE BOUNDARY

FIG. 2-4B.
EXISTING
CONDITIONS—
CONTOURS

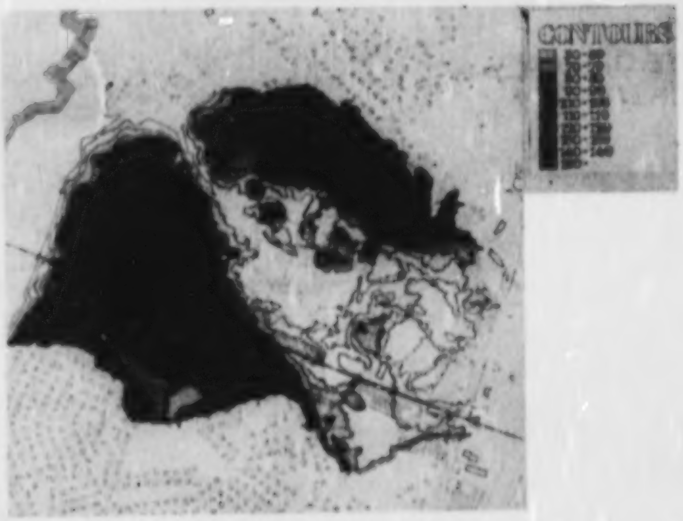


FIG. 2-4C.
EXISTING
CONDITIONS—
SLOPES

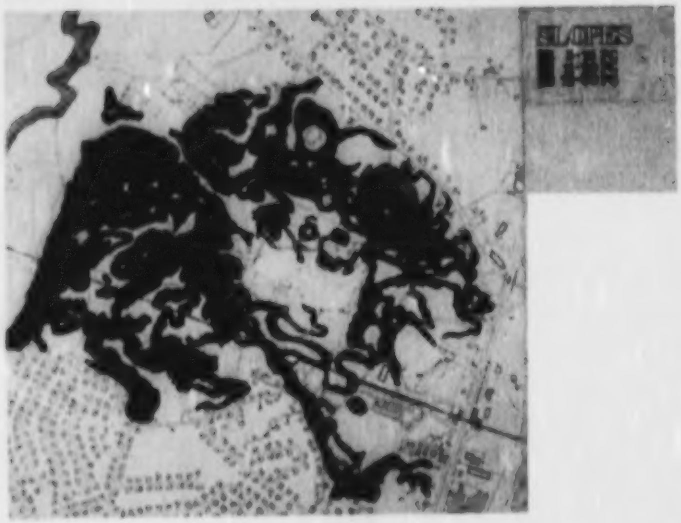


FIG. 2-4D.
EXISTING
CONDITIONS—
SUPERFICIAL
GEOLOGY

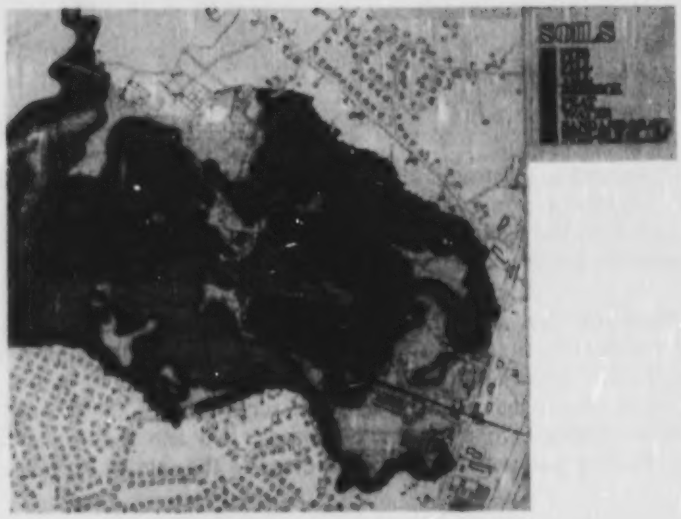


FIG. 2-4E.
EXISTING
CONDITIONS—
VEGETATION

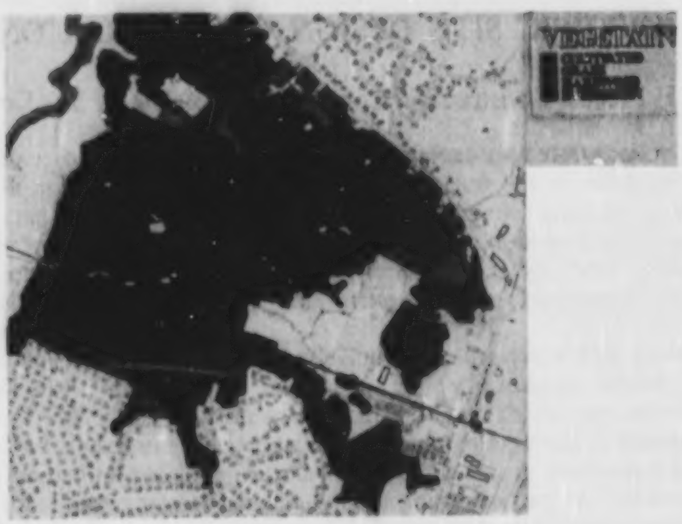


FIG. 2-4F.
EXISTING
CONDITIONS—
VIEWS

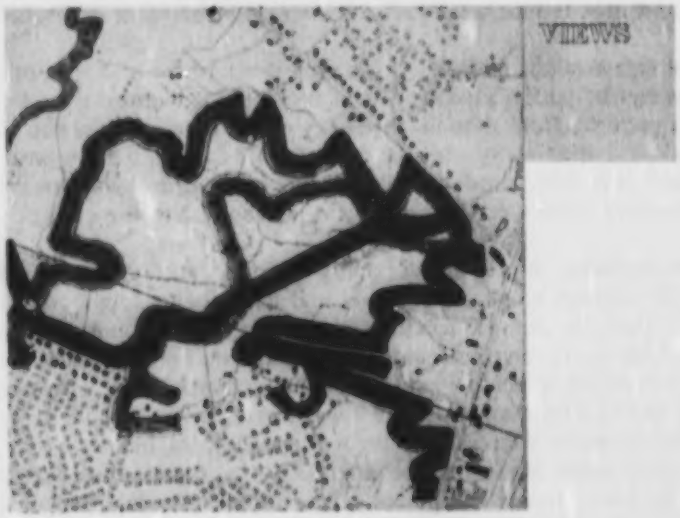


Fig. 2-4g and h illustrates schematic choices which the designer must make in the final site plan. Alignment of the influent line and service water can follow many routes. The designer must refer to the earlier site inventory drawings, to ascertain the impact of each choice on the sensitive site areas.

The final site design (Fig. 2-4i) illustrates how the designer has managed to fit the large areas required for treatment processes within the portion of the site suitable for such development. In this hypothetical southern climate, snow melting is not a problem; thus truck and parking areas can be arranged to allow separation of visitor and employee parking. Visitors would be shielded from truck and process areas and led to a special administrative building entry. Facility personnel would park close to the service building.

2.3 SPECIFIC SITE DESIGN CONSIDERATIONS

2.3.1 Process Construction Considerations Affecting Site Development

SITE TOPOGRAPHY AND GEOLOGY. For sites which are sloped, a site plan which will facilitate gravity flows in the process should be considered. Reduction of pumping requirements by such a hydraulic strategy can save both capital and operating costs, as well as conserve energy. Existing slopes should be respected in construction planning, to limit erosion and siltation. Similarly, if particularly good soils for fill or excavation exist on the site, the plan should attempt to use these resources, to minimize construction costs.

COMPACT SITE PLANNING. A relatively compact site plan can minimize piping requirements and thereby reduce pumping energy and costs. Particular attention should be paid to the distances over which materials like sludge must be conveyed. A compact plan will also limit the extent of site development—a desirable feature in tight urban areas where open land may be at a premium or in sensitive rural sites where intrusion in ecologically sensitive areas is to be avoided. As part of compact planning, manned areas and work stations should be grouped to allow centralization of process equipment and personnel facilities in a single major building and thus reduce total staff size and optimize plant supervision and operation functions.

ODOR AND AEROSOL SOURCES. Known potential odor and aerosol sources in treatment process areas can be partially controlled, if they are located downwind (according to the prevailing wind pattern) from near neighbors or public spaces on the site. Such process elements could be located near each other or be covered. In conjunction with the topographic and wind information, odor producers should not be sited in valleys or other areas where natural air movements cannot produce sufficient air changes to dissipate odors rapidly (see chapter 3).

NOISE SOURCES. Noise in the facility buildings and on the site should be controlled, to prevent discomfort to plant personnel and nuisance to neighbors. Process and auxiliary equipment, such as pumps, ejectors, generators, and vacuum assemblies, which can produce disturbing sound levels should be isolated from personnel areas and work stations wherever feasible. Noise levels from such machinery should be investigated for compliance with U.S. EPA and OSHA requirements for wastewater facility employee exposure to noise. In facility buildings, noise sources can be segregated from quieter areas by acoustic barriers, and offending noise levels can be attenuated by sound absorbing materials. Transmission of sounds from process equipment offsite should also be controlled. Road alignments on the site should be designed to eliminate steep grades, so that noises from truck braking and

FIG. 2-4G. PLANNING FACTOR—SEWER ALIGNMENTS

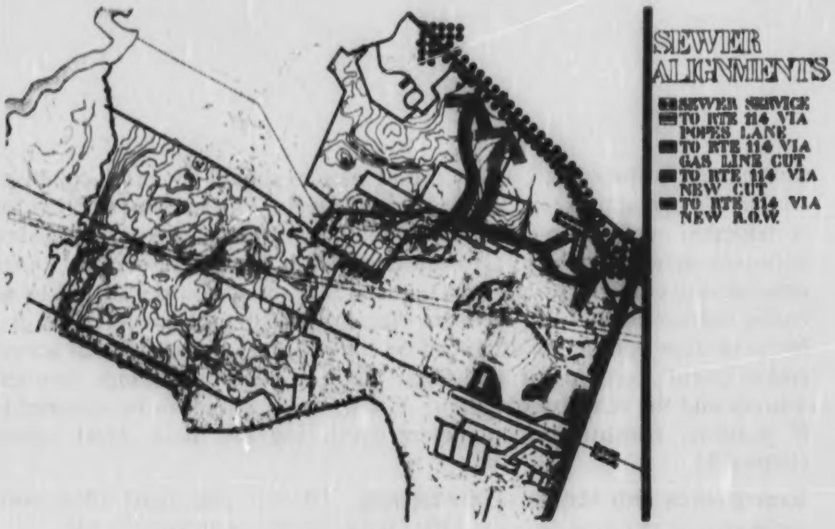

SEWER ALIGNMENTS
SEWER SERVICE
TO RTE 114 VIA POPES LANE
TO RTE 114 VIA GAS LINE CUT
TO RTE 114 VIA NEW CUT
TO RTE 114 VIA NEW R.O.W.

FIG. 2-4H. PLANNING FACTOR—WATER ALIGNMENTS

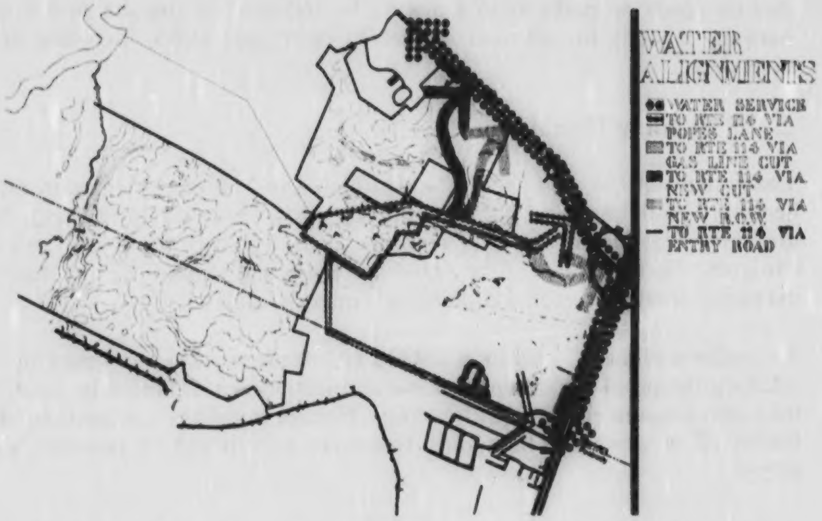
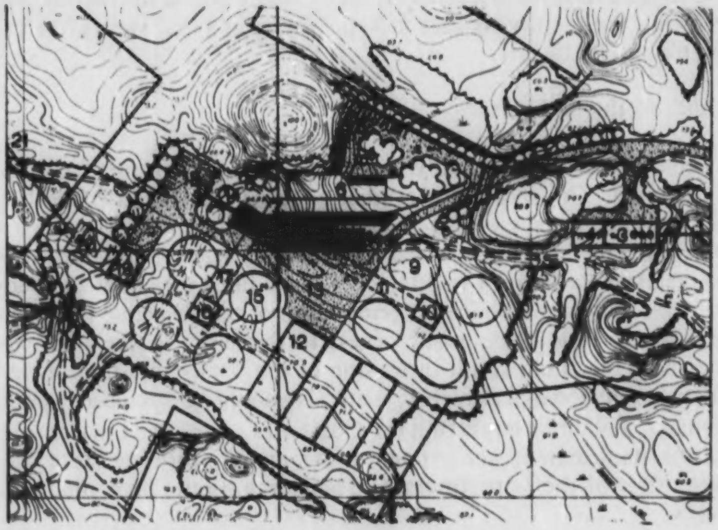

WATER ALIGNMENTS
WATER SERVICE
TO RTE 114 VIA POPES LANE
TO RTE 114 VIA GAS LINE CUT
TO RTE 114 VIA NEW CUT
TO RTE 114 VIA NEW R.O.W.
TO RTE 114 VIA ENTRY ROAD

FIG. 2-4I. FINAL SITE DESIGN



LEGEND
1. Influent
2. Entry road
3. Grit screenings building
4. Grit chambers
5. Visitors car park
6. Administration
7. Solids handling
8. Service facilities
9. Primary sedimentation
10. Primary pump gallery and access structure
11. Primary tunnel
12. Aeration basins
13. Trucking yard
14. Gravity thickeners
15. Final clarifiers
16. W.A.S. pump gallery and access structure
17. Tunnel
18. Employee car park
19. Chlorine building
20. Chlorine contact basins
21. Effluent

Reproduced from best available copy.

shifting can be avoided. Facility sound sources should not produce noise levels offsite which regularly or greatly exceed ambient sound levels. The simplest method for sound attenuation is reduction at the source (for every doubling of distance, sound pressure levels decrease by approximately 6 decibels). However, a facility cannot always be located well away from noise-sensitive neighbors. In such cases, onsite sound sources should be acoustically isolated. Noise sources in buildings can be placed inside sound barriers and absorptive enclosures. Noise sources outside buildings can be controlled by placing partial acoustic barriers, such as embankments, very dense plantings, and the facility buildings themselves, between these sources and the sensitive neighbors. Construction noise can be screened in a similar manner. If possible, construction equipment producing low noise levels should be chosen (see chapter 4).

MAINTENANCE AND ACCESS REQUIREMENTS. The site plan must allow normal and emergency maintenance to be carried out in the facility buildings and on the site.

Access roads or paths should always be included in the site planning, and their size and bearing capacity for all maintenance or emergency tasks, including fire fighting, should be considered.

2.3.2 Building Orientation

The climate of the area should be considered in building orientation and design. To control heating, ventilating, and air conditioning costs, major building faces should be oriented to minimize heat loss in the cold season and heat gain in the warm season through openings, windows, skylights, etc. The building enclosure should be carefully designed to avoid excessive energy use for the building's internal climate.

In northern climates, buildings should not shade trucking and parking areas, thereby exacerbating the problems of winter snow and ice clearance. Similarly, landscape planting should take into account shade from buildings. Neither buildings nor landscaping should shade open bodies of wastewater undergoing treatment but should, if possible, prevent wind cooling action.

Buildings should be located to serve as barriers to undesired views of the facility. For instance, the designer may locate the facility so that it limits the neighbors' view of the facility and presents an acceptable public face.

2.3.3 Shoreline and Wetlands Planning

The shoreline of the body of water usually associated with wastewater facilities should be respected in site planning. The shore is a critical zone in the earth's natural system—the place where land, air, and water meet. It is also a prime recreational zone, and thus site planning of a wastewater facility should consider means by which shorelines within the site boundaries can be reserved for public use. Fig. 2-5a and b illustrates how an adequate public way along a shore drive can be maintained. Preservation of the shoreline is especially important in urban areas where little open public access to the shore is likely to exist. Because construction at the shoreline could result in erosion of the banks, siltation of the waterway, and destruction of valuable ecological niches, methods should be specified where necessary, to prevent such damage. Facilities impacting the Coastal Zone must be in conformance with the Coastal Zone Management Act (Appendix A), and appropriate State officies and the appropriate office of the Department of Commerce should be contacted during environmental review.

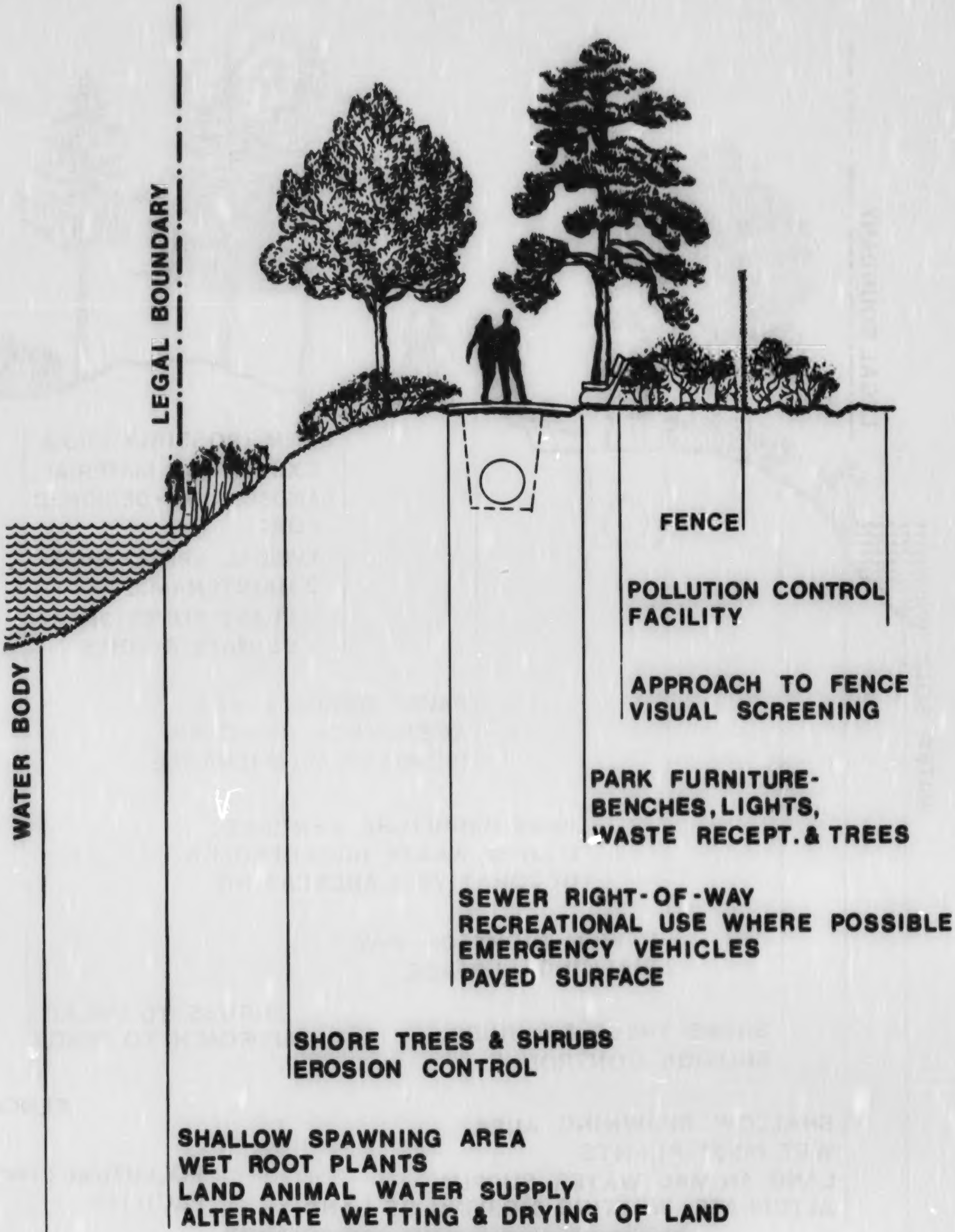

LEGAL BOUNDARY
WATER BODY
FENCE
POLLUTION CONTROL FACILITY
APPROACH TO FENCE
VISUAL SCREENING
PARK FURNITURE-
BENCHES, LIGHTS,
WASTE RECEPT. & TREES
SEWER RIGHT-OF-WAY
RECREATIONAL USE WHERE POSSIBLE
EMERGENCY VEHICLES
PAVED SURFACE
SHORE TREES & SHRUBS
EROSION CONTROL
SHALLOW SPAWNING AREA
WET ROOT PLANTS
LAND ANIMAL WATER SUPPLY
ALTERNATE WETTING & DRYING OF LAND

FIG. 2-5A. SHORELINE PLANNING

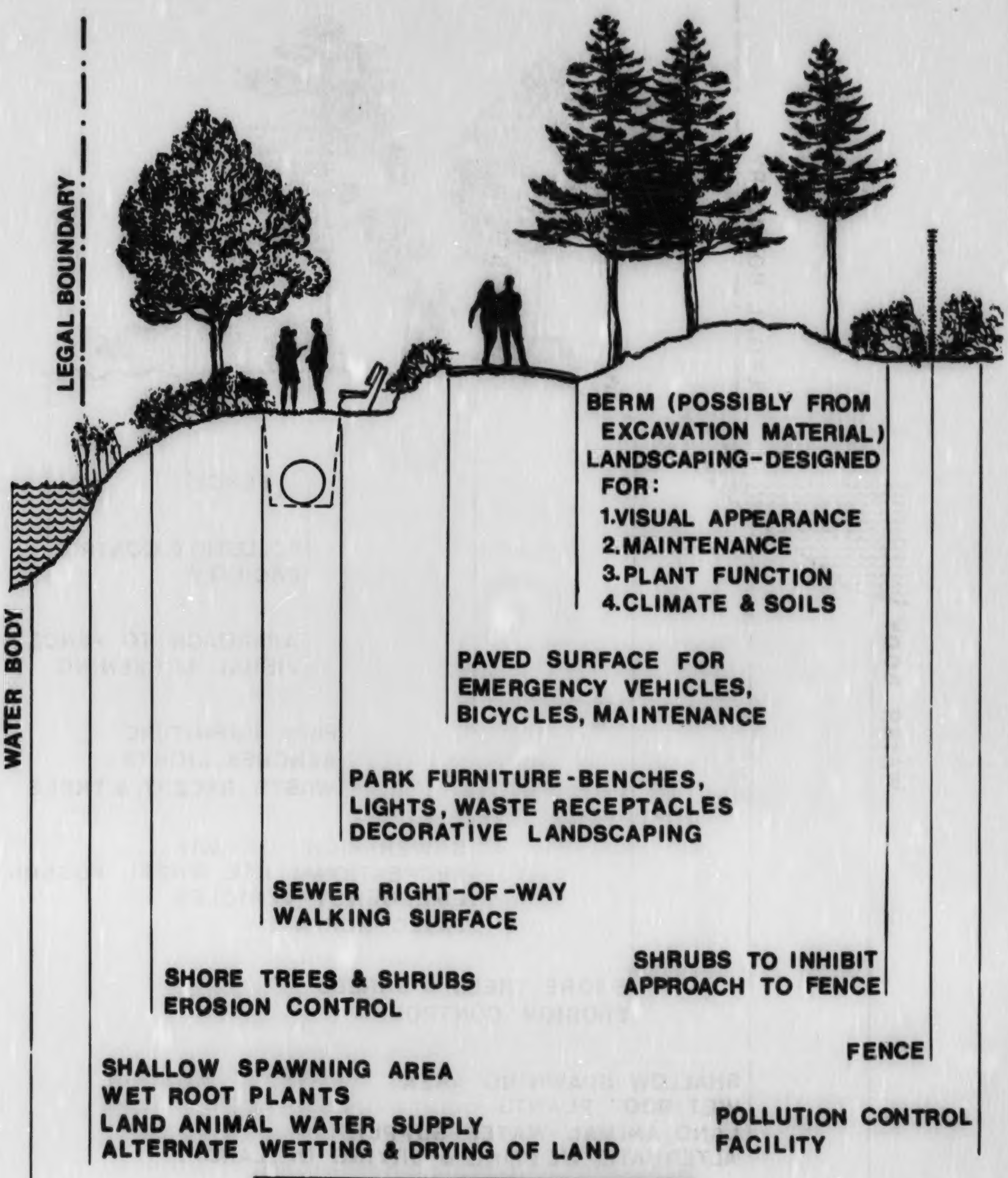

LEGAL BOUNDARY
WATER BODY
BERM (POSSIBLY FROM EXCAVATION MATERIAL)
LANDSCAPING-DESIGNED FOR:
1.VISUAL APPEARANCE
2.MAINTENANCE
3.PLANT FUNCTION
4.CLIMATE & SOILS
PAVED SURFACE FOR EMERGENCY VEHICLES, BICYCLES, MAINTENANCE
PARK FURNITURE-BENCHES, LIGHTS, WASTE RECEPTACLES DECORATIVE LANDSCAPING
SEWER RIGHT-OF-WAY WALKING SURFACE
SHRUBS TO INHIBIT APPROACH TO FENCE
SHORE TREES & SHRUBS EROSION CONTROL
FENCE
SHALLOW SPAWNING AREA
WET ROOT PLANTS
LAND ANIMAL WATER SUPPLY
ALTERNATE WETTING & DRYING OF LAND
POLLUTION CONTROL FACILITY

FIG. 2-5B. SHORELINE PLANNING

Wetlands are another unique and valuable resource and must be protected from alteration of the quantity or quality of the natural water flow. If facility construction and operation might produce such an effect, the appropriate offices of the Department of the Interior, Department of Commerce, and the U.S. Army Corps of Engineers should be contacted to determine the probable impact on the pertinent fish and wildlife resources and land use of the wetlands. Administrator's Decision Statement #4 (Appendix A) describes EPA wetlands policy.

2.3.4 Flood Plain Avoidance

Flood plain boundaries of a site should always be determined prior to site design. If possible, siting within a flood plain should be avoided. Building in the flood plain necessitates raising the facility entry above flood level and safeguarding facility elements against flood damage, flotation effects, and process interruption. Also, for every cubic foot of flood plain volume occupied, flood levels are raised correspondingly. Thus flood effects are worsened by flood plain encroachment. Any facility siting must be in conformance with Executive Order 11296 and the Flood Disaster Protection Act (see Appendix A).

2.3.5 Recreation and Education

The Wild and Scenic Rivers Act (see Appendix A) defines three classifications for selected rivers: wild, scenic, and recreational. Water resources projects, such as treatment facilities, may be prohibited where a direct and adverse effect would result on the values for which such rivers were established. Facility planners should avoid where possible siting on one of these designated waterways. Designation and classification of rivers may be obtained from the Bureau of Outdoor Recreation (Interior) or the National Forest Service (Agriculture).

Only those portions of the site necessary for facility operation should be dedicated to the wastewater facility itself. Other portions of the site should be reserved for other public uses, particularly recreation (for example, along waterways). The facility buildings themselves should be designed to provide opportunities for public education concerning the wastewater facility, its operation, and its role as a public utility.

A public entrance to the facility site which will lead clearly to a public entry to the main facility building should be provided. At this entry point, an appropriate educational display can be located or a tour of the facility can begin. If public education is to be part of the facility function, then educational displays should be designed to be clear, accurate, and informative. If frequent tours of the facility are to be accommodated, then safe, complete, and easily followed paths through the facility should be included in the site and building designs.

2.3.6 Wildlife Habitats and Historic Sites

The Endangered Species Act (Appendix A) provides for the conservation of threatened or endangered flora and fauna. It is important that endangered species and their critical habitats adjacent to or directly affected by the proposed site be identified.

Project sites must be evaluated for the presence of archaeological, historical, or other cultural properties included on or eligible for inclusion in the National Register of Historic Places. This is required by the National Historic Preservation Act of 1966 and Executive Order 11593

(Appendix A). If such properties are identified and will be adversely affected by the project, the procedures of the Advisory Council on Historical Preservation (Appendix A) must be followed and means developed to mitigate the adverse impacts. The State Historic Preservation Officer should be consulted during this process.

2.3.7 Landscaping

Existing site vegetation should be assessed. If it can remain undisturbed throughout construction, it should be safeguarded, because its destruction will only require later planting to return the area to an acceptable condition.

Existing or newly planted vegetation can be used as a visual screen for process elements and buildings. Of course, the value of the screen must be assessed for all seasons and throughout the natural history of the planting. Planting should be considered for control of slope erosion and water runoff, and to emphasize architectural or site forms, so that it can frame attractive objects as well as hide unattractive ones. In considering major planting for any purpose, views to, from, and on the site must be carefully studied. Planting can be designed to shade processes, buildings, paths, and truck yards in summer and still allow effective use of winter light. If landscaping elements are to be used, the local soil, climatological, and biological conditions should be carefully investigated by a competent landscape architect or nurseryman, before investment is made in fragile vegetative materials. Materials requiring little or no maintenance are to be preferred over those requiring a higher degree of care. Planting near open basins should be designed so that leaves and needles do not fall or cannot be easily blown by the wind into process waters.

References such as the U.S. Department of Interior's publication *Plants/People* and *Environmental Quality* by G.O. Robinette may be consulted on landscape and planting design.

2.3.8 Lighting

Design standards and techniques are well established for both interior and exterior lighting systems, to provide adequate light for safe operation, efficiency, and security. These are briefly described below.

INTERIOR LIGHTING. Architectural and engineering reference texts provide adequate design standards for the interior lighting required for a good working environment. *Illuminating Engineering Society Lighting Handbook* is a basic reference.

EXTERIOR LIGHTING. Exterior lighting should be based on analysis of ambient light levels in the area. Possibly adverse impacts of the proposed lighting on the area should be assessed, including consideration of annoyance, loss of privacy, and resulting decline in property values.

SAFETY LIGHTING. Redirecting lights necessary for safe operation without diminishing light on the work area is desirable, if there might be an adverse impact on adjacent areas. Corrections may be accomplished by spotlighting specific areas. Shielding the lighting will also result in a lower light level outside the working area.

SECURITY LIGHTING. High light levels which permit ready visual observation for security purposes are rarely necessary.

AESTHETICS. Lighting may be used to highlight structural and landscape features.

CONSTRUCTION LIGHTING. Construction lighting may be classified as that necessary for construction operations and that needed for security during construction. Care should be taken to eliminate light spillover onto adjacent land, if such spillover would adversely affect land use. Spillover effects should be based on ambient light levels and land use in the adjacent areas. Light from moving vehicles may be blocked by temporary barriers. Security lighting, to permit surveillance of parked equipment, can be minimized by parking equipment in a limited remote area or by parking equipment in areas already lighted.

If security lighting during construction will intrude on adjacent residential areas or on other areas which might be detrimentally affected, the designer may specify that these be lighted in a manner to eliminate or reduce nuisances. Specifications should include direction of lighting, height of light, and intensity.

2.3.9 Security

A wastewater facility can attract children, with its tanks of water and unfamiliar processes. It is also an essential public service which must be safeguarded against vandalism and damage. For these reasons, access to the facility should be controlled. Fences and other barriers should enclose the facility in a way unoffensive to the public eye. If the facility is near an important public way or close to a sensitive neighbor, then a specially designed barrier—garden wall or landscaped buffer with hidden fence, for example—should be provided. Security considerations need only apply to the immediate area bordering the facility, not to the entire site. If possible, walls of process elements and buildings themselves should enclose the facility, minimizing fencing requirements. If process and building walls form part of the security boundary, their materials should be chosen to resist whatever forms of vandalism can be expected at the site.

2.3.10 Building Aesthetics

As important public structures of high utilitarian and monetary value, wastewater facility buildings deserve forthright and careful architectural treatment. Because they are planned for long-term public service, their design, materials, and construction should show them to be permanent additions to the community. If the building is not to be screened from view, the public face of the structure should be designed to express the building's public utility capacity and to reflect society's pride in its works.

Building design should not hinder process function but should order the workings of plant personnel, process equipment, and visitors. Such quality of design is not easily achieved, and competent architectural designers should be employed whenever possible.

In residential neighborhoods, the scale of the wastewater facility should closely match that of other public facilities nearby. Siting and views of the wastewater treatment facility should be studied fully, so that it can be reduced in apparent scale as much as possible. A reduced visual scale and minimal functional presentation is a good strategy for building design in sensitive areas.

2.3.11 Future Development

Site design must include provision for future expansion of the facility, if that will be required. A good site design for future development requires more than simple designation of adequate area for expansion. Expansion areas should be chosen so that future construction can occur without interruption of existing facility processes. In other words, neither construction nor its access should interfere with regular plant operation. Locating future expansion areas for different elements near each other can facilitate expansion construction. Flexibility should also be allowed in plans for expansion.

Future changes in process equipment and processes themselves cannot be predicted with certainty; thus the site plan should not be rigidly adapted to one particular process and incapable of future alteration without excessive construction and operation penalties. Areas designated for future expansion need not be reserved behind the facility fence. Because expansion may not occur for many years, and may not occur in the manner originally planned, reserved areas may be temporarily dedicated to other public uses such as public open spaces or recreation.

2.3.12 Site Traffic

Trucks and service traffic should be separated from operation and employee traffic early and easily upon site entry. Visitors should be directed to an appropriate building entry. Employee and visitor traffic in truck yard areas should be limited, wherever feasible. Truck traffic should also be clearly routed.

Truck turning and backing areas should be sized for the largest vehicle expected. Pedestrian traffic onsite should not have to cross the truck yard or process areas to enter buildings.

3. AIRBORNE POLLUTANTS

3.1 GENERAL INFORMATION

Airborne pollutants from a wastewater treatment facility, if sufficiently concentrated or intense, can make the facility environmentally incompatible with neighboring land uses.

The purpose of this chapter is to familiarize the designer with the characteristics of possible airborne pollutants, to provide measurement techniques for determining the pollutant's strength, to discuss acceptable pollutant levels, to summarize control technology and the locations where each technology can be used, and to illustrate design calculations with examples. There are many areas and processes in wastewater facilities which can be potential sources of airborne pollutants, if such pollution is not prevented by satisfactory design, construction, operation, and maintenance. Airborne pollutants include: odors; noxious, toxic, or asphyxiating gases; particulates from sludge incinerators and construction operations; and aerosols from trickling filters, aeration basins, cooling towers, stripping towers, ventilation systèms, and construction operations.

Recently, aerosols have been shown to be deserving of attention. Pathogens present in aerosols must be considered a potential source of disease and infection, because aerosols have been found to include *E. coli, A. aerogenes,* and pathogenic enteric organisms *(1, 2, 3, 4, 5,)*. No evidence, however, has been found that aerosols have affected the health of either wastewater facility workers or others.

Controls for particulates and gases from incinerators are well established *(6)(7)*. EPA has developed criteria and standards for permissible levels of pollutants in stack emissions *(8)*. These standards established limits on particulate discharge and opacity.

Gases which can cause air pollution are emitted from many locations in treatment works, including: wastewater, sludge, and liquid sidestream processing; wastewater collection, pumping, and transmission; and disposal operations. Some of these gases are explosive, toxic, asphyxiating, and/or flammable. Dangerous gases are discussed in reference *(9)*.

3.2 ODORS

3.2.1 Units of Expression

Units of expression used in odor discussions are defined as follows *(14)*:

1. *acuity*—keenness of the sense organs in detecting qualitative or quantitative differences among stimuli
2. *adequate stimulus*—one which normally elicits a response with a particular sense concern
3. *anosmia*—total or partial lack of sensitivity to odor stimuli
4. *attitude*—acquired predisposition to respond in a consistent way toward a given class of objects; a persistent state of readiness to react to a certain object or class of objects, not as they are, but as they are conceived to be
5. *attribute*—any quality or characteristic descriptive of stimulus
6. *contrast*—presentation of two different stimuli which results in emphasizing their contrary characteristics; may be of two types: (a) simultaneous or (b) successive
7. *detection threshold*—minimum physical intensity detection by a subject if subject is not required to identify the stimulus but just detect the existence of the stimulus
8. *difference threshold*—physical difference between two stimuli which can be correctly judged as subjectively different beyond chance expectation
9. *intensity*—quantitative attribute of stimuli roughly correlated with strength of stimuli; odor intensity is a sensation, not a concentration, and is measured on a psychological reaction scale
10. *masking*—in odor applications, situation in which one quality within a mixture dominates or overrides another quality or other qualities present, thus changing the quality or intensity
11. *odor*—perception of smell referring to the experience, or that which is smelled referring to the stimulus (*odorant* is preferred for this latter usage)
12. *odor counteraction*—nonchemical odor phenomenon in which two individually discernible odors yield, upon mix-

ture, a third odor which is weaker in intensity than either of the original two odors

13. *odor unit*—quantity of odorous substance or combination of substances which, when completely dispersed in 1 cubic foot of odor-free air, is detectable by a median number of observers in a panel of eight or more persons *(12)*

14. *odorant*—substance which stimulates olfactory receptors

15. *odor panel*—group of individuals who may be selected on the basis of sensitivity to stimuli, reliability, or whose perceptions are judged to be representative of some larger population; used to obtain information concerning the subjective attributes of physical stimuli

16. *subjective*—pertaining to experience which can be observed and reported only by the person involved; that is, mental phenomena usually verbally reported

17. *threshold odor*—minimum physical intensity of stimulus which elicits a response 50 percent of the time.

3.2.2 Odor Potential at Wastewater Treatment Facilities

A 1974 telephone survey of 500 wastewater collection and treatment system superintendents indicated that about 40 percent of the systems had received complaints about odor and about 34 percent had instituted measures to control odors *(13)*.

Any organic material containing sulfur and/or nitrogen in domestic wastewater can, in the absence of an oxygen source, undergo incomplete oxidation, resulting in the emissions of byproducts which may be malodorous. For this reason, a major effort must be given to the prevention of odorant production and to the control of odors which can be generated accidentally, by the careful design and operation of wastewater treatment works.

The degree of obnoxiousness of malodorous gases depends not only on the concentration of the odor and on the person exposed to the odor but also on the intensity of the odor. Most people are particularly sensitive, and have greater acuity, to unfamiliar odors. Olfactory sensitivity varies from person to person. The olfactory senses of persons continually exposed to an odor become anosmic or insensitive to that odor with time; therefore, odor nuisance determinations are highly subjective. In fact, gases such as H_2S rapidly affect the olfactory senses to such an extent that, after a few minutes' exposure to even low concentrations, a person can no longer detect the H_2S. Environmental engineers, or plant operators, regularly associated with the operation of a wastewater treatment plant and who may be at least partially anosmic to the plant's odors should not be the ones who judge whether or not their treatment plant has an odor problem.

Odors that can be identified as having come from domestic waste are particularly objectionable to most people. Even *fresh* wastewater and *digested sludge* have odors which, although not objectionable to environmental engineers or treatment plant operators, are often unacceptable to the general public. Potential sources of wastewater odors include:

1. fresh, septic, or incompletely treated wastewater
2. raw or incompletely stabilized sludge
3. raw or incompletely treated liquid process sidestreams
4. screenings, grit, and skimmings containing septic or putrescible matter
5. oil, grease, fats, and soaps from industry, homes, and street runoff
6. gaseous emissions from treatment processes, manholes, wells, pumping stations, leaking containers, turbulent flow areas, and outfall areas
7. chlorinated water containing phenols
8. dredged or excavated material containing odor producing substances
9. incompletely oxidized hydrocarbon fuels with high sulfur content.

There are innumerable odors in airborne gases and vapors resulting from various concentrations and intensities of each odorous constituent. As these odorous gases and vapors travel downwind, they often are neutralized (by counteraction) or to some extent intensified by reaction with other gases, vapors, or particulate matter.

3.2.3 Characteristics of Odors

Inorganic gases and organic vapors result from biological activity. The more common inorganic gases associated with domestic wastewater treatment facilities include hydrogen sulfide (H_2S), sulfur dioxide (SO_2), ammonia (NH_3), carbon dioxide (CO_2), methane (CH_4), nitrogen (N_2), oxygen (O_2), and hydrogen (H_2). Only hydrogen sulfide, sulfur dioxide, and ammonia are malodorous.

The most frequently emitted odors found in the studies of some 300 wastewater treatment works *(14)* were: methylmercaptans, methylsulfides, and amines, followed by indole, skatole, hydrogen sulfide, and, to a lesser extent, sulfur dioxide, phenolics, and chlorine compounds. Some organic acids, aldehydes, and ketones may also be odorous either individually or in combination with other compounds. The mild, musty odor often found near treated sludge is caused by algae, fungi, and molds continuing the organic decomposition processes.

The concentration of an odorant is measured in milligrams per liter (mg/l) or micrograms per liter (μg/l); the intensity is a measure of the stimulation of the olfactory senses. Odor intensity or strength does not vary proportionally with the concentration of the odorant. The intensity of an odor at a concentration of 100 may be only twice as great as its intensity at a concentration of 10 *(15)*. The intensity of an odor may be decreased by the same ratio whether the concentration is reduced from 50 mg/l to 25 mg/l or from 10 mg/l to 5 mg/l.

Complete oxidation of odorants usually results in complete eradication of odor. Incomplete oxidation may result in an increase in odor. For example, butanol has a mild odor and, upon complete oxidation, is changed to odorless CO_2 and H_2O. However, if it is incompletely oxidized, it is successively changed to butyraldehyde and then butyric acid, both of which have strong odors.

To prevent odors when organic compounds are decomposed, the oxidation-reduction potential (ORP) of the wastewater or sludge must be maintained sufficiently high for complete oxidation, to avoid the formation of partially oxidized products such as H_2S, NH_3, mercaptans, skatoles, indoles, etc. Common oxidizing agents, in decreasing order of their half-ORP (ORP/2) in volts, are ozone (2.07), hydrogen peroxide (1.77), permanganate (1.70), chlorine (1.36), oxygen (1.23), iodine (1.20), bromine (1.07), nitrate (0.94), sulfate (0.17), and hydrogen (0.00). For the ORP to remain sufficiently high to avoid incomplete oxidation of organic compounds containing sulfur, oxidizing agents must be added if the amount of oxidizing agents normally present in wastewater—oxygen (O_2) or nitrate (NO_3)—is not adequate. Other oxidizing agents, such as chlorine, ozone, pure oxygen, hydrogen peroxide, and oxides of nitrogen, also raise the ORP when added to wastewater. In sufficient concentrations, these agents can cause completely odor-free oxidation.

Warm wastewater, under anaerobic conditions with a low ORP and a pH of about 6 to 8, will produce odors that have been characterized by different people as rancid, fecal, cabbagelike, skunklike, etc., depending on the predominant odorant. Some of the characteristics of the more common odorants found near wastewater or sludge are presented in Table 3.1.

3.2.4 Hydrogen Sulfide

Sulfur (ORP/2 = 0.14) is present in human excreta, and sulfates are found in most water supplies. Therefore, sufficient sulfur is normally available in domestic wastewater, in the form of inorganic sulfides or organic sulfides (e.g., mercaptans, thioethers, and disulfides), for the production of odorous gases or vapors by anaerobic and facultative bacteria.

Hydrogen sulfide (H_2S) is the most commonly known malodorous gas emanating from domestic wastewater collection and treatment facilities. H_2S is highly soluble (2,800 mg/l at 30° C to 5,650 mg/l at 5° C) in normal domestic wastewater. In addition to its rotten-egg odor, H_2S can cause highly corrosive conditions and is an extremely toxic substance. The walls and crowns of sewers or closed tanks often have droplets of attached spray or condensation on the surface. Water (such as condensed water vapor in the form of dew or droplets) saturated with H_2S as a result of bacterial action forms sulfuric acid, which is very corrosive to lead-based paint, concrete, metals, and other materials. The toxicity of H_2S is on the same order of magnitude as hydrocyanic acid (HCN). Death appears to have resulted from an H_2S concentration of 0.03 percent in the air *(18)*. The maximum permissible 8-hour H_2S concentration is about 0.001 ml/l *(10)*. H_2S is treacherous, because the ability of a person to sense it is quickly lost. If the person ignores the first notice, the senses will no longer give warning and the person may be killed *(18)*.

TABLE 3-1. ODOROUS VAPORS FOUND AT WASTEWATER FACILITIES*

Substance (Odor Description)	Formula	Molecular Weight	Odor Threshold, μg/l	Normal Boiling Point, °C at 760 mm Hg
Ammonia (sharp and pungent)	NH_3	17.03	37	–33
Ethyl mercaptan (decayed cabbage and garlic)	C_2H_6S	62.1	0.2	23
Hydrogen sulfide (rotten eggs)	H_2S	34.1	1.1	–62
Indole (excreta)	C_8H_6NH	117.1	—	254
Methyl mercaptan (decayed cabbage and onions)	CH_3SH	48.1	1.1	8
Skatole (fecal, pungent, and irritating)	C_9H_9N	131.2	9.0	266
Dimethyl amine	$(CH_3)_2NH$	45.08	4.7	7
Methyl amine	CH_3NH_2	31.06	21.0	–7
Dimethyl sulfide	$(CH_3)_2S$	62.13	2.5	37
Chlorophenol (medicinal)	ClC_6H_5O	128.56	0.18	214
Chlorine (pungent, irritating)	Cl_2	70.91	10	–34
Allyl mercaptan (garlic)	$CH_2{:}CH{\cdot}CH_2{\cdot}SH$	74.15	0.05	67
Diphenyl sulfide (unpleasant)	$(C_6H_5)_2S$	186.28	0.05	296
n-butyl mercaptan (skunk)	$CH_3{\cdot}CH{:}CH{\cdot}CH_2{\cdot}SH$	90.19	0.03	98
Ozone (slightly pungent, irritating)	O_3	48	1	–111.3

---

*See references *(7, 15, 16, 17)*.

If wastewater is kept in a force main or siphon for more than a few minutes, sulfides may be formed, particularly if the temperatures are high. The possible buildup in a filled pipe can be estimated roughly, using the following formula *(19)*:

$$\Delta C_s = 0.0026tC_{EBOD}\,\frac{(1 + 0.01d)}{d}$$

where

ΔC_s = sulfide concentration increase, mg/l
t = detention time, min
C_{EBOD} = effective BOD = $1.07^{(T-20)}$ (BOD_5), mg/l
T = temperature, °C
d = pipe diameter, in.

At a pH of about 9, hydrogen sulfide dissolved in water is over 99 percent in the form of the nonodorous sulfide ion (HS^-) but only 1 percent at a pH of about 5. If the pH is above 8, there is little trouble from H_2S gas.

H_2S is most commonly produced by reduction of the sulfate ion (SO_4^{2-}) by anaerobic sulfate-reducing organisms. These bacteria thrive at low oxidation-reduction potentials (ORPs of –0.20 to –0.30 V), pH of about 6 to 9, and temperatures near 30° C. The ORP of fresh wastewater is usually too high for the first one or two days for significant production of H_2S. However, anaerobic slime growths and sludge deposits which accumulate in sewer lines usually have lower ORPs than the wastewater, making them more conducive to H_2S production. H_2S may thus be produced even though the wastewater contains up to about 0.3 mg/l of O_2 and the ORP is not sufficiently low to support sulfate-reducing organisms. If nitrates or dissolved oxygen is present and well distributed, the ORP will be too high for H_2S production by sulfate reducers.

For more details on methods to prevent and control hydrogen sulfide, see references *(4, 15, 18, 20–23, 25–32)*. References *(15)* and *(18)* are particularly valuable.

3.2.5 Standards or Acceptable Levels

Standards, or acceptable levels, of odors from wastewater treatment plants normally have not been set, because any odor traceable to such works is deemed excessive. For this reason, it has been the practice to surround wastewater treatment plants with open ground or natural barriers such as forests, rivers, major highways, etc. However, treatment facilities built in open country may in time be surrounded by populated areas whose residents undoubtedly will insist on freedom from detectable odors from the facilities. As a result, wastewater treatment facilities should be designed and built so that, if odors become detectable outside the plant site, alleviation will be easily attained.

Designing for odor control requires that the engineer assess the effect of the odor on adjacent land use, as well as on the workers at the facility. Significant criteria are frequency and intensity of occurrence related to the population affected. For example, the effect of an odor on a residential area will be substantially different from the effect on some heavy industrial area where some odor is already present. In certain cases, costs of providing odor control will be minimal, because safety requirements dictate effective venting of units, and only odor elimination equipment installations will be required to process the odorous gas.

3.2.6 Odor Detection and Measurement

Absolute identification of all ingredients of an odor is not necessary. To date, no instrument can better measure odors than the human nose, because odor is a physiological response to a complex grouping of airborne compounds. In fact, no known mechanical device can quantitatively measure the intensity of combined odors. The concentration of the primary components of some odorous compounds, such as hydrogen sulfide or sulfur dioxide, can be monitored. However, because of variations in composition of the ingredients of the gas, it is very difficult to correlate intensity findings from the individual odor concentrations. Odor measurement for odor abatement purposes can be made more easily and accurately at the source, because the characteristics of the odorous vapors and gases often change with movement downwind, by diffusion and by combination with other gases or vapors.

Each attempt to measure a strong odor may cause some olfactory fatigue and loss of acuity in the tester, thus reducing the accuracy of subsequent trials. Continued testing is more accurate if the nose is intermittently subjected to only diluted odors. For this reason, strength or intensity of an odor is best established by determining the number of dilutions with odor-free air required to reduce the odor from a sample to a barely detectable level. The dilution should be prepared by other than the odor testers, or some time should elapse after most of the necessary dilution has been completed before the final threshold determination is made.

The sensitivity of the olfactory senses varies considerably from person to person, and the interpretation of odors is very subjective. It is thus necessary to have several persons who are known to be sensitive to all expected types of odors make the tests. It has been found that persons with discriminating food tastes are also usually more sensitive to odors *(7)*. The detectability of odors will increase with increases in temperature and humidity at the time of testing. Some odors, such as the earthy odor of polysulfides formed when H_2S is treated with chlorine, are only released when wastewater is heated.

The odor unit is the amount of odor necessary to contaminate 1 cubic foot of odor-free air to the detection threshold level; i.e., the odor is detectable by a median number of observers in an odor panel. For example, if it takes 9 cubic feet of an air sample to reduce the odor to the threshold level, the air sample contains 10 odor units per cubic foot. Total odor units emitted are equal to the odor units per cubic foot times the cross-sectional area in square feet of the odor emission times the velocity of emission in feet per minute.

Four methods, based on human perception of odors, are normally used for measuring odor concentrations *(7)*:

1. Odor-free air and odor-containing air are mixed in a container, and samples of the mixture are injected into the tester's nose.

2. Odor-free air and odor-containing air are mixed in a container, and the tester inhales from the container.

3. Odor-free air and odor-containing air are mixed in a duct from which a flow of the mixture is discharged to a nosepiece, headpiece, hood, or chamber for sniffing by the tester.

4. Odor-free air and odor-containing air are mixed in a measurable dilution, utilizing the energy exerted in the process of inhalation.

The major differences in these methods have to do with preventing odorous vapors from being deposited on the equipment or in the nostrils of the testers, thus interfering with subsequent tests.

For detailed descriptions of the odor testing methods, see references *(7, 32, 34)*. Discussions of selection of odor panel members and the procedures to be followed are contained in references *(7, 21, 33, 34, 35)*.

3.2.7 Odor Analysis Methodology

References *(33, 36, 37, 38)* contain descriptions of methods used to qualitatively and quantitatively analyze odorous gases. However, because two or more of these odorants may combine to produce either a weaker or stronger odorant, the quantitative measurement of the component odorants in an odorous gas or vapor is of little value.

For this reason, methods of measuring strength of odors must rely on the olfactory nerves of odor panels described in the previous section. These measurements can be correlated with the quantitative findings of gas chromatography.

Table 3-1 lists the threshold concentrations of the more common odorants found at domestic wastewater treatment plants.

3.2.8 Odor Control Measures

Odor control measures should take into account the following: (a) completely aerobic oxidation of organic matter prevents the formation of odorous compounds of sulfur and nitrogen; (b) slime buildup on conduit and tank walls, and sludge or organic waste deposits, will almost always produce some H_2S and other odorants; and (c) H_2S and other odorants will be released from wastewater at points of turbulence, particularly where freefall occurs.

Dague *(15)* listed the various factors which should be considered in the control of wastewater odors: (a) all normal people can smell; (b) some substances are odorous, others are not; (c) we can smell at a distance; (d) substances of different chemical constitution may have similar odors; (e) substances of similar constitution usually have similar odors (however, isomers or even stereoisomers may have different odors); (f) substances of high molecular weight are usually not odorous and often nonvolatile or insoluble; (g) the quality as well as the strength of an odor may change on dilution; (h) the sense of smell is rapidly fatigued; (i) fatigue for one odor will not affect the perception of other dissimilar odors but may interfere with the perception of similar odors; (j) two or more odorous substances may cancel each other out (on the other hand, two or more mildly odorous substances may add together to form a very odorous substance); and (k) odors travel downwind.

Measures which have been successful in the prevention or control of odors generated at wastewater facilities are described in the following paragraphs.

OXIDATION/DISINFECTION. This is usually accomplished with such chemicals as chlorine, ozone, hydrogen peroxide, and sodium permanganate.

Chlorination. Chlorine gas and hypochlorite solutions have been successfully used to stop the action of odorant producing bacteria and to oxidize odorants such as H_2S and mercaptans *(12, 18, 40)*, by injecting chlorine or hypochlorite into wastewater or by passing collected odorous air through a chlorine solution in a tank. It takes about 5 g (2.1 to 8.87 g) of chlorine to 1 g of H_2S to inhibit odor production *(39)* and often as much as 10 to 15 g to convert all the sulfur to sulfates, because of the other more easily oxidizable compounds present *(18)*. If Cl_2 dosages are down to about 2.1 g/g of H_2S, hydrochloric acid is formed; if Cl_2 dosages are up to about 8.4 g/g of H_2S, both hydrochloric and sulfuric acids are formed. Each of these is very corrosive. In many locations, to prevent damage to downstream ecological systems, it may be necessary to dechlorinate and remove those chlorinated compounds which are toxic before the treated wastewater is discharged. Some odors are not removed by chlorination. If the odorous compound concentration is above the design concentration, other odorous compounds may be formed. Chlorine supresses bacterial activity even in a combined form, but most bacterial populations, including the coliform population, will often be regenerated shortly after the chlorine residual disappears *(54)*. For more information on odor control with chlorine, see reference *(18)*. Chlorine application is discussed in reference *(53)*.

Ozonation. Ozone is used to oxidize odorants in air, collected from above wastewater processes, before discharge to the atmosphere *(40)(41)*. Ozonation of wastewater has not been practiced to a great extent in the past; however, recent developments, including the possible dangers of chlorine compounds and the reduced costs of newer ozonators, make the use of ozone in place of chlorine feasible for both odor control and disinfection, particularly if the wastewater must also be dechlorinated. Active research is being sponsored by the EPA, to develop better design criteria for the safe use of ozone. Oxidation of airborne odorants with ozone may present a hazard if ozone remains in the treated air in concentrations above 0.2 mg/m^3 of air at the time of discharge *(42)*. Further information on odor control with ozone is contained in reference *(51)*. Ozone application is discussed in reference *(53)*.

Hydrogen Peroxide. Hydrogen peroxide is another oxidant used to destroy sulfate-reducing bacteria in sewers and to oxidize any sulfides present *(31)(32)*. In recent years, hydrogen peroxide has been used in place of prechlorination, to prevent hydrogen sulfide buildup in transmission lines and pumping stations and to prevent hydrogen sulfide problems in wet wells *(18)*. It is usually necessary to first condition (oxidize slimes and organic deposits on walls) the pipes and tanks in which the wastewater is to be treated by one or more dosages of 50 mg/l for 4 to 8 hours. Following one or more of these massive treatments, dosages can be lowered to 5 to 10 mg/l to prevent H_2S formation. Between 1 and 2 lb of H_2O_2 are needed per pound of H_2S after the slug dosages *(39)*. H_2O_2, like ozone, raises the dissolved oxygen content of the wastewater in addition to killing sulfate-reducers and reducing odors. H_2O_2 is competitive in price with chlorine for control of H_2S *(39)*.

Sodium Permanganate. Sodium permanganate, like ozone and H_2O_2, is a significantly more active oxidizing agent than chlorine. However, it is generally not competitive with respect to cost with other oxidizing agents *(12, 22, 40)*. In some cases, the manganese content of the water may be increased to a troublesome level.

RAISING THE ORP. To prevent the production of odorants by sulfate reducers and other anaerobes, air, nitrates, and pure oxygen have also been added to wastewater to raise the ORP.

Air. **Wastewater is commonly aerated by mechanical aerators, diffusers, a free fall which causes turbulence, and U-tube aeration. The addition of air to prevent anaerobic conditions in wastewaters will prevent the production of odorants. The addition of air to anaerobic wastewater may strip out odorants and thus cause odor problems if not adequately controlled, particularly at drops or falls in septic wastewater streams. Sufficient air must be dissolved and confined sufficiently long for oxidation of sulfides to be accomplished. U-tubes with air addition by aspirators have proved to be an effective and odor-free method of adding air to wastewater lines. A detailed description of aeration methods is presented in reference *(18)*.**

Oxygen. **If a main has little rise, making air injection relatively feasible, pure oxygen may be used as an alternative for sulfide control in force mains and siphons, if the oxygen can be kept in solution *(18)*.**

Nitrate. **This chemical has been satisfactorily added to wastewater to reduce and temporarily control odors. Nitrate may serve to prevent sulfide buildup by preventing sulfate reduction, because nitrate-reducing bacteria can use nitrate to oxidize sulfide, if oxygen is not available *(18)*.**

pH CONTROL. If sulfide odors predominate, it is possible to reduce or eliminate hydrogen sulfide by raising the pH. At pH above 9, H_2S is not present, but biological treatment processes will be substantially impeded *(6)*. Caustic soda or quicklime used to raise the pH of wastewater in sewers to 13 will inactivate the slime on sewer walls for about 1 week *(18)*. Because sulfide producers can adjust to pH over 10.5, the pH should not be held above 9 for more than 30 minutes.

ABSORPTION/SCRUBBING. Odor removal by reactive scrubbing can be an effective method of odor control, particularly if followed by activated carbon or ozonation, depending on the odorous components of the gas. Potential scrubbing reagents are $KMnO_4$, NaClO, Cl_2, ClO_2, and $NaHSO_3$. However, a single scrubbing reagent can seldom remove all odorous compounds effectively *(12)*. The efficiency of odor removal can often be improved by increasing the pH of the scrubbing solution *(12)*. The resulting solution, however, must be amenable to treatment in a wastewater treatment plant or pretreated to make it so. Scrubbers are best suited for treating large volumes of air containing relatively low concentrations of odorous contaminants. Possible advantages of scrubbers include: capability of installation in a low building, because conventional scrubbing towers are not needed; gravity flow of solution; quiet operation; and reasonable cost, because this equipment is mass-produced. Possible disadvantages include: necessity for auxiliary processes such as adsorption or filtration, corrosion of equipment, and maintenance of minimum concentration of reagent. See reference *(51)* for further information on scrubbing. Low concentrations of odorants may be removed by bubbling the polluted air through activated sludge or water with a high dissolved oxygen content.

ADSORPTION. Adsorption with activated carbon can be an effective and economical odor control method for emissions from wastewater treatment facilities containing a low concentration of odorous compounds *(12)*. The odorous gases and vapors must be collected, as for ozonation, and then passed through the adsorbent beds of activated carbon. Adsorbent beds should be continuously monitored, because the activated carbon may have a low capacity for some odorants and, without regeneration, a short adsorbent life with respect to those odorants *(12)(23)*. In Sacramento, where a large treatment plant became closely surrounded by a better-than-average residential area, it was found that sodium hypochlorite scrubbers followed by carbon adsorption units successfully removed all odors *(43)*. Further information on odor control using activated carbon is contained in reference *(51)*.

Adsorption-absorption using soil beds has proved to be an effective way of treating odorous gases collected at pumping stations *(15, 44, 45)*. A carbon filter was included in one installation for backup but was not needed during the first year of operation *(44)*. Warm, moist, loamy soils are necessary for effective odor removal in soil beds.

INCINERATION—CATALYTIC AND DIRECT FLAME. Fumes from wastewater treatment works can be deodorized using direct flame. Incineration at an adequate temperature for a sufficient time oxidizes organic compounds to odorless water and carbon dioxide and relatively odorless oxides of nitrogen and sulfur. At temperatures below 1,400° F, partial oxidation may result, with the production of highly odorous gases. To accomplish complete oxidation, 3 seconds at 1,400° F is sufficient detention time *(15)*. To ensure that all parts of the burning chamber have temperatures above 1,400° F, it is well to have the control thermostat set to operate between 1,550° and 1,600° F. Above 1,750° F, dangerous oxides of nitrogen may be formed and cause air pollution. Incineration can be effective in controlling highly concentrated odors in low volumes of air *(12)(22)*. In some cases, if particulate matter is present, incineration should be preceded by condensers or dust collectors *(12)(22)*. Catalytic oxidation operates at temperatures from 1,000° to 1,300° F. The lower cost for fuel is offset by the catalyst replacement cost, particularly if the odorous gas is corrosive to the catalyst. Advantages of direct flame incineration with respect to catalytic oxidation are lower maintenance costs, less downtime, and better odor destruction. Advantages of catalytic oxidation are lower temperatures, lower operating costs, lighter construction, and better removal of particulates and aerosols. Steam plumes from incinerators can be controlled using condensers or afterburners. Emission standards for wastewater treatment incinerators are contained in reference *(52)*.

DESIGN MEASURES. Prevention of odor nuisance conditions should be considered in the design of any conduit or basin which will contain wastewater or sludge. Some important design elements and operational practices to consider include:

1. Locate the facility on a well ventilated site to prevent odor accumulation, not in a hollow or where it will be surrounded by trees.

2. Provide for sufficient mixing, to ensure scouring velocities over the entire floor of aeration basins and to prevent sludge accumulation in corners where velocities are too low.

3. Enclose locations of turbulent flow, where odorants or aerosols might escape from anaerobic wastewater or sludge, to prevent escape of odorants and to collect them for oxidation before discharge to the atmosphere. Such locations may include headworks, primary clarifiers, trickling filters, sludge thickeners, sludge dewatering tanks, and sludge holding tanks.

4. Provide high pressure connections for hoses, for use in the daily flushing of walls and corners to prevent any accumulation of slime or sludge.

5. Provide adequate slopes in all conduits, whether open or closed, to ensure scouring velocities once a day.

6. Provide for mechanical cleaning of all closed conduits, if slopes are not sufficient to ensure daily scouring velocities.

7. Provide for U-tube aeration of anaerobic wastewater in manholes upstream of pumping stations or treatment facilities, or a means of adding hydrogen peroxide, chlorine, or hypochlorite, if the sulfide problem is too much for simple aeration, to prevent escape of odors at the pumping station or treatment facility headworks.

8. Provide aeration in distribution channels, to maintain aerobic conditions as well as to ensure homogeneity of the organic material in the wastewater.

9. Provide for returning a portion of the waste activated sludge to the headworks, to assist in reducing odors.

10. Provide for pneumatic or other enclosed transfer of screenings or other odorous compounds to the disposal point.

11. Provide a vacuum cleaner truck for cleaning grease traps, screening boxes, scum boxes, and catch basins and carrying their odorous contents in an enclosed tank to the disposal point.

12. Provide an adequate section in the facility operation and maintenance manual on odor control. This should include procedures: for daily flushing to remove slime and sludge accumulations, for checking for sufficient conditioning of sludge before its discharge to open drying beds or use as fertilizer on lawns, for cleaning all sludge discharge pipes and areas immediately after use, for preventing overuse of treated wastewater for irrigation, and for using sulfuric acid or caustic soda for removing slime or lime encrustations.

13. Provide requirements in the sewer ordinance for removal, or for reduction to a treatable level, of all industrial waste compounds which might cause odor problems at a properly operated wastewater facility.

Suggested measures to be considered during design, to prevent odor and control or reduce the possibility of odor nuisances, are presented in Table 3.2.

TABLE 3-2. POSSIBLE ODOR PREVENTION AND CONTROL METHODS

	Gravity Sewers	Force Mains	Pumping Stations	Treatment Plant Headworks	Grit Handling and Disposal	Screenings Handling & Disposal	Equalization Tank	Primary Clarifier	Flotation Units	Scum Handling and Disposal	Sludge Holding	Sludge Thickening	Sludge Digestion	Sludge Dewatering	Sludge Incineration	Process Sidestream	Aeration Tanks	Trickling Filters	Stabilization Ponds	Secondary Clarifier	Granular Media Filters	Polishing With Screens	Septage Manhole	Sludge Drying Beds & Lagoons	Conditioned Sludge Storage	Lawns Irrigated w/Wastewater	Effluent Structure
PREVENTION																											
Enforcement of good sewer ordinance	X	X	X	X	X	X				X													X				
Regular inspection and maintenance	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Disinfection																											
Oxidizing agents																											
Hydrogen peroxide	X	X	X	X			X	X								X		X		X		X	X			X	X
Ozone			X	X			X	X								X		X		X		X				X	X
Chlorine	X	X	X	X			X									X					X	X				X	X
Potassium permanganate	X	X																									
Alkalinizing agents																											
Lime*											X	X	X	X		X											
Sodium hydroxide	X		X	X			X									X											
Maintain O_2 source in wastewater																											
Forced ventilation	X		X	X														X					X				
Discharge waste activated sludge to unit inlet			X	X			X	X															X				
Dilution with aerated wastewater							X												X								
Aeration	X	X					X					X				X	X										
Oxygenation																X	X										
Sodium nitrate	X	X	X																								
Zinc sulfate	X	X	X																								
Prevent sludge aging and deposits																											
More frequent solids withdrawal					X	X		X	X	X	X									X			X	X	X		
Complete mixing in tanks			X				X				X	X					X										
Sufficient velocity in flows	X	X	X	X												X											
Smooth transitions in structures	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
Regular cleaning	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
Miscellaneous																											
Equalization of flow							X	X	X							X	X	X		X		X					
Pretreat at previous units					X	X	X	X	X								X	X			X						
Reduce loading on unit																	X	X	X		X		X	X	X	X	
Raise temperature to over 1,600° F															X												
Give special treatment before return																X											
CONTROL																											
Enclose and vent																											
Structure			X	X		X		X		X	X	X	X	X	X			X		X	X	X	X	X	X		X
Dome						X		X		X	X	X		X				X		X	X	X	X	X	X		X
Floating cover													X														
Separate room in building			X	X		X		X		X	X	X		X						X		X	X				
Add chemicals to odorous wastewater																											
Hydrogen peroxide	X	X	X	X				X										X		X			X				
Ozone	X	X	X	X				X										X		X							
Chlorine	X	X	X	X				X																			
Activated carbon	X	X	X	X		X		X																			
Zinc sulfate	X	X	X	X		X		X																			
Sodium nitrate	X	X	X	X		X		X																			
Treat vented gases before discharge**																											
Ozonation			X	X		X		X		X	X	X		X				X		X	X	X	X	X	X		X
Combustion at over 1,600° F				X		X		X		X	X	X	X	X				X		X	X	X	X	X	X		X
Wet scrubbing				X		X		X		X	X	X		X	X			X		X	X	X	X	X	X		X
Catalytic oxidation				X		X		X		X	X	X		X	X			X		X	X	X	X	X	X		X
Vent through activated sludge tank				X		X		X		X	X	X		X				X		X	X	X	X	X	X		X
Activated carbon adsorption			X	X		X		X		X	X	X		X				X		X	X	X	X	X	X		X
Treated wood chip adsorption			X																								
Filter through soil bed			X																				X				X
Disinfect effluent																			X								X
Pretreat influent	X	X	X	X			X	X									X	X			X		X	X	X	X	

*Lime should not be used where sludge is incinerated.

**Piping, vents, diffusers, etc., must be corrosion resistant.

3.2.9 Odor Intensity Determinations

The transmission of any detectable odor to an inhabited location may be detrimental to the value of that location. Determination of possible odor transmission from wastewater treatment facilities is usually limited to studies of those conditions conducive to the transmission of the maximum odor concentrations expected under adverse conditions.

Turbulence of air movement increases dispersion, decreases odor concentrations, and decreases the probability of odor nuisances. Three factors lead to increases in turbulence: vertical temperature profile, surface topography, and wind velocity.

If the temperature decreases with height (a temperature lapse) at a rate lower than adiabatic, which is defined as about 5.4° F per 1,000 ft (about 1° C per 100 m), vertical air movements are damped or reduced and an inversion exists. If the lapse rate is more than adiabatic (more than 5.4° F per 1,000 ft), vertical air movement is increased.

Ground roughness increases from flat unforested farmland to suburban low-rise construction areas to urban multistoried areas (the rougher the ground, the more turbulence). Turbulence also increases with ruggedness of terrain. In flat country, for instance, turbulence caused by rural conditions might reach about 250 ft (76 m). In suburban areas, this height could increase to 350 or 400 ft (107 or 122 m), while in the high-rise part of central cities the height could increase to 500 ft (152 m) or more. In hilly or mountainous country, the heights of increased turbulence would tend to be even greater than over flat land.

Air turbulence increases with an increase in wind velocity, variations in velocity from average, and variations in wind direction. In general, an increase in wind flow or its gustiness in comparison with the average gradient wind velocity creates a corresponding increase in turbulence.

Six classes of stability categories established by the EPA *(35)* are given in Table 3.3. Class A is the most unstable, class F the most stable. Night refers to the period from 1 hour before sunset to 1 hour after sunrise. Note that the neutral class, D, can be assumed for overcast conditions during day or night, regardless of wind speed.

TABLE 3-3. KEY TO STABILITY CATEGORIES

Surface Wind Speed (at 10 m), m/sec	Day			Night	
	Incoming Solar Radiation			Thinly Overcast or $\geq 4/8$ Low Cloud	$\leq 3/8$ Cloud
	Strong	Moderate	Slight		
<2	A	A–B	B		
2–3	A–B	B	C	E	F
3–5	B	B–C	C	D	E
5–6	C	C–D	D	D	D
>6	C	D	D	D	D

The following material on dispersion is largely based on Turner's workbook on atmospheric dispersion estimates *(46)*. The concentration χ of odorous gases or aerosols from a continuous ground level *point* source resulting from atmospheric dispersion (if the plume spread is considered to have a Gaussian distribution, as shown on Figs. 3-3, 3-4, 3-5, and 3-6) along the centerline of a plume at ground level with no effective plume rise and minimum turbulence (from surface topography or gusty winds), utilizing Turner's diffusion equations *(46)*, can be expressed:

$$\chi = \frac{Q}{\pi \sigma_y \sigma_z u} \qquad \text{(Eq. 3-1)}$$

where

χ = concentration, in odor units per cubic meter χ km downwind
u = wind speed, in meters per second
σ_y = standard lateral deviation (wind with Gaussian distribution) of odor particles across the plume, in meters (see Fig. 3-1)
σ_z = standard vertical deviation (wind with Gaussian distribution) of odor particles across the plume, in meters (see Fig. 3-2)
Q = average emission rate of odor-causing vapor, in odor units per cubic meter

Eq. 3-1 can be used to determine whether an odor of known strength from a source might be detected and in what amount at a specific location downwind of the source.

Similarly, the concentration of odorous gases or aerosols in odor units per cubic meter at a point downwind during inversion conditions (for limitations, see reference [*35*]) from a continuous ground level *area* source, utilizing Turner's diffusion Eq. 3-1, can be expressed:

$$\chi(x, y) = \frac{Q}{\pi \sigma_y \sigma_z u} \exp\left[\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \qquad \text{(Eq. 3-2)}$$

where χ = concentration at points x, y
x, y = downwind and horizontal crosswind coordinates, respectively, in meters
σ_y, σ_z = standard lateral and vertical deviations of wind (see Figs. 3-5 and 3-6), in meters
exp ("a") = e (or 2.7183) raised to the "a" power; for this example, e is raised to $\frac{1}{2}(y/\sigma_y)^2$

Eq. 3-2 would be used after the cross-section of a plume near the source had been tested to determine the odor concentration Q at a theoretical point source.

In either case, odor tests would be required to determine the threshold odor concentration. On a calm, cloudless day in rural areas, inversion conditions start near the ground at sunset and grow in intensity and depth during the night, reaching a maximum near sunrise. The inversion then starts decreasing at the ground level so that, by about 9:00 AM, there would only be an inversion layer somewhere between 500 to 1,000 ft (about 150 to 300 m). Under similar wind conditions, the atmosphere is more stable on clear summer nights.

3.2.10 Sample Calculations

POINT ODOR SOURCE. Sometimes, odors are collected in a treatment plant structure and vented through a stack above the roof. This would be considered a point odor source. In the case of an existing plant, it is not difficult to measure the flow of gas from the stack and, by regular sampling, determine the maximum strength of the odor to be expected. For new plant

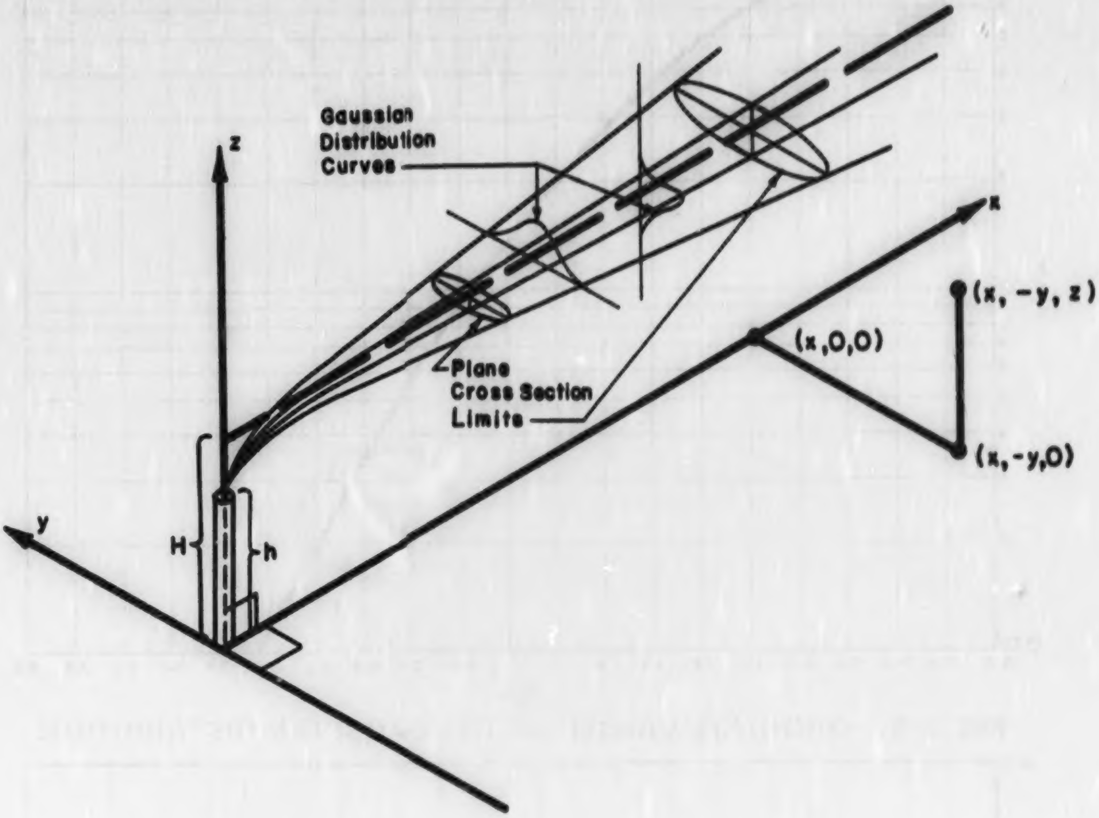

Gaussian
Distribution
Curves
z
x
y
(x, −y, z)
(x,0,0)
(x, −y,0)
Plane
Cross Section
Limits
H
h

FIG. 3-I. GAUSSIAN DISTRIBUTIONS

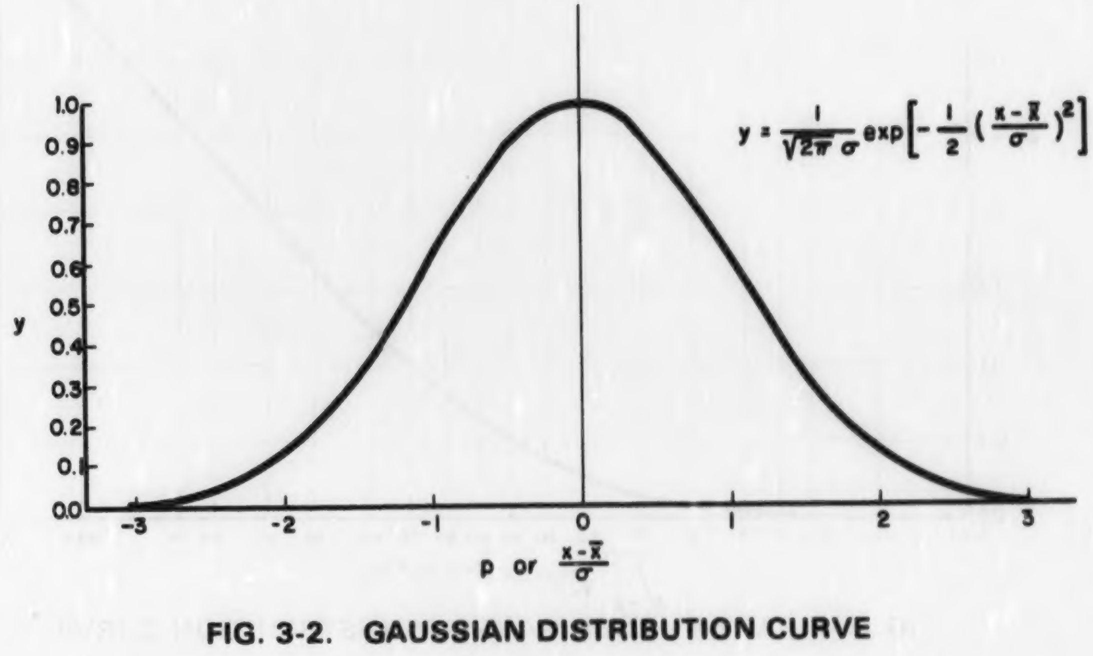


FIG. 3-2. GAUSSIAN DISTRIBUTION CURVE

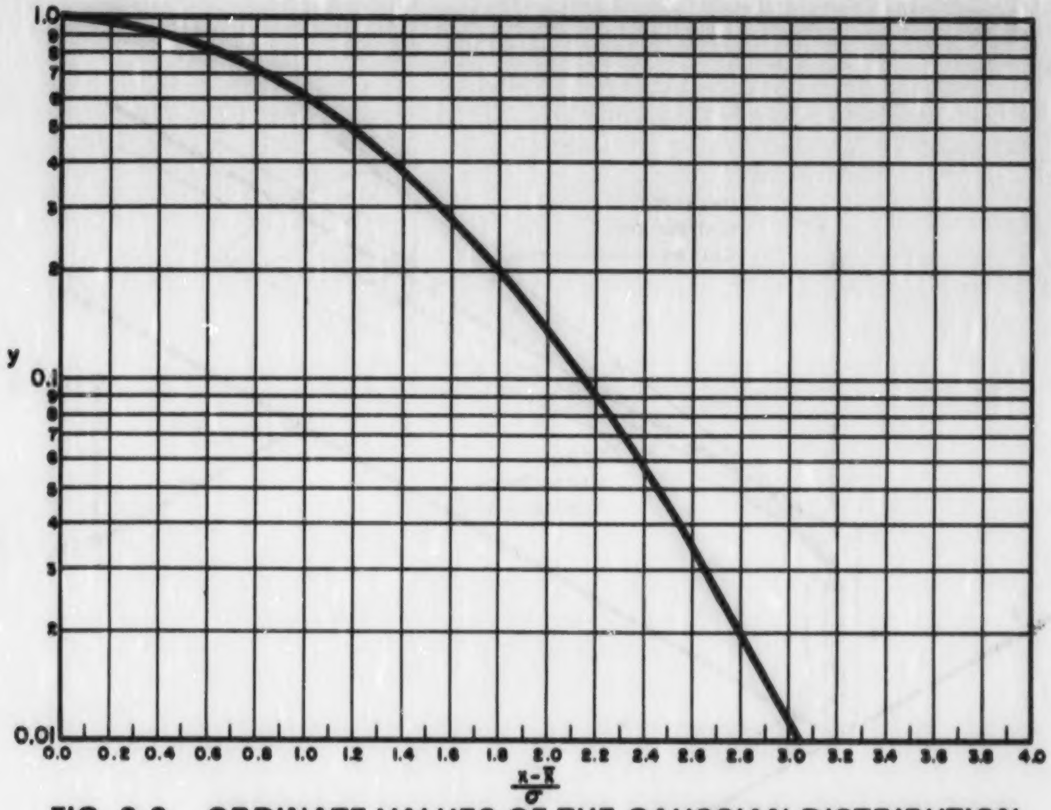


FIG. 3-3. ORDINATE VALUES OF THE GAUSSIAN DISTRIBUTION

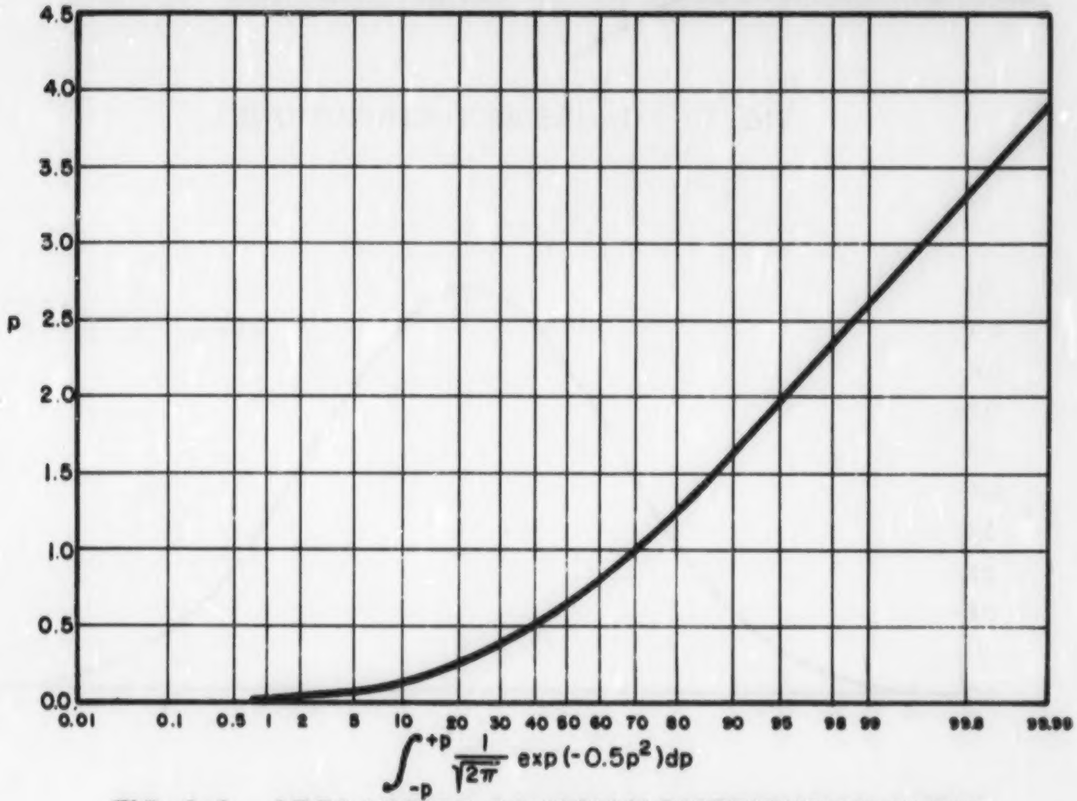


FIG. 3-4. AREA UNDER GAUSSIAN DISTRIBUTION CURVE

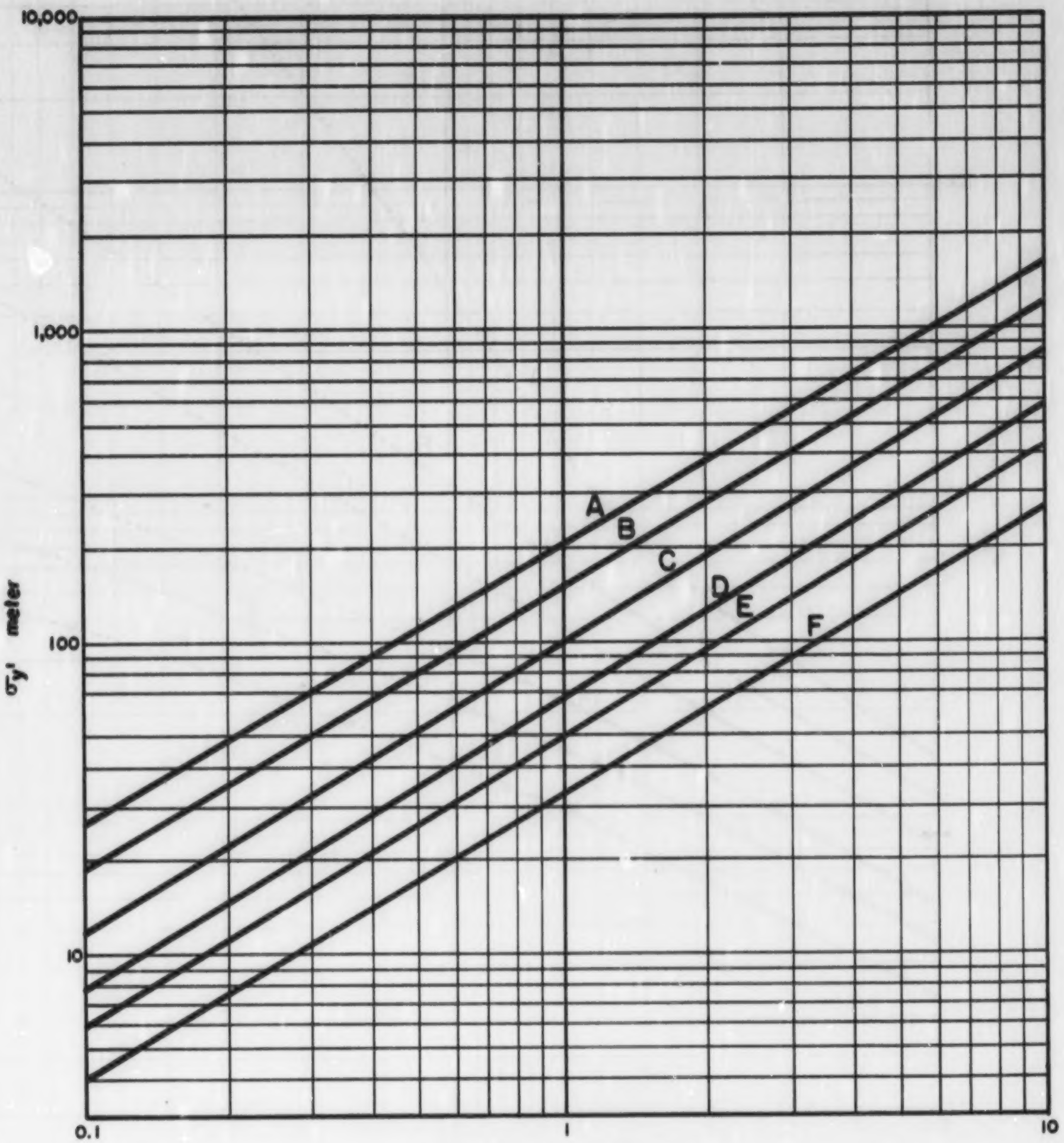


FIG. 3-5. HORIZONTAL DISPERSION COEFFICIENTS

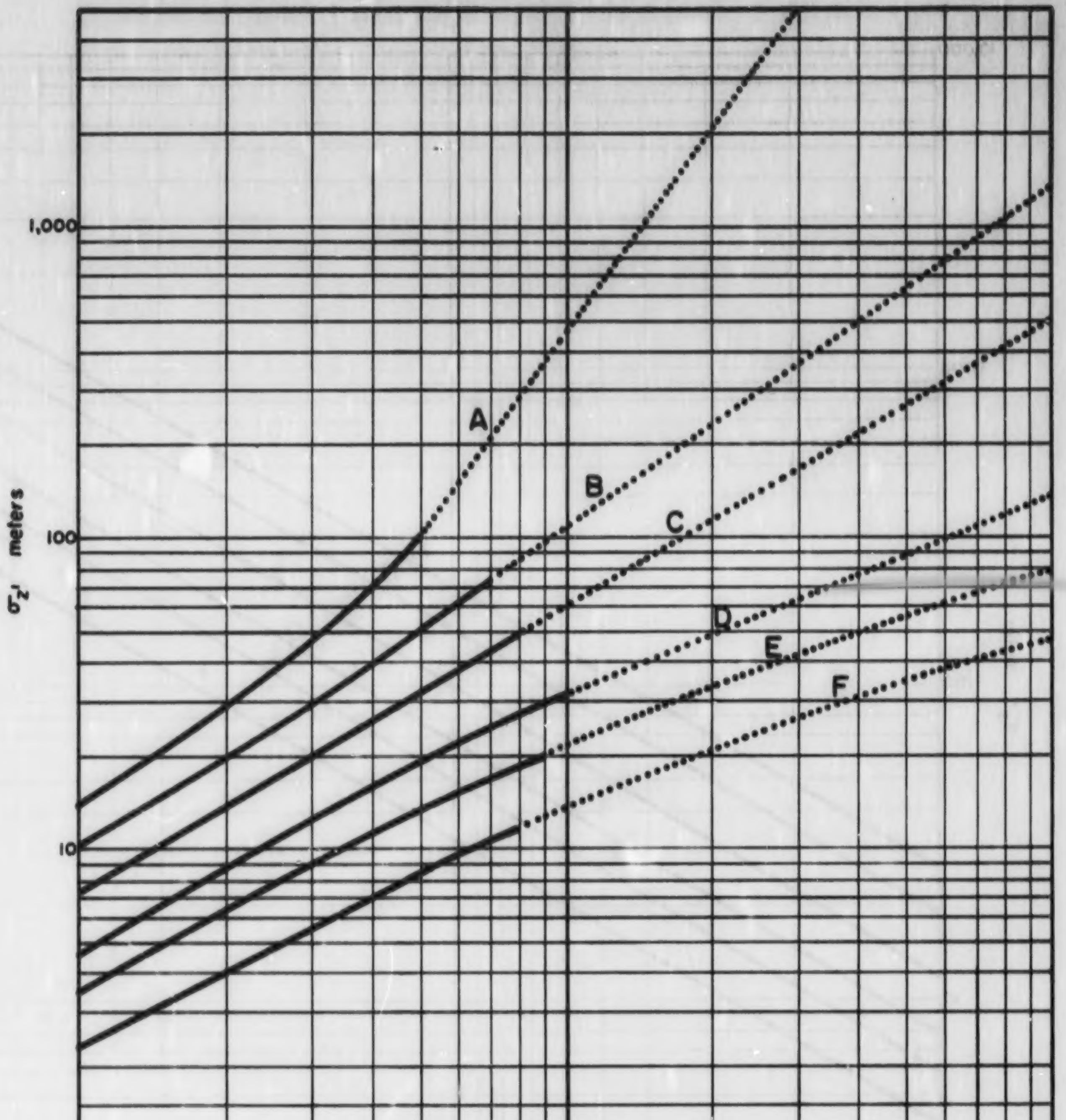


FIG. 3-6. VERTICAL DISPERSION COEFFICIENTS

design, until better data are available, it is best to test an existing similar plant to determine odor strengths. If there are more than one stack, the normal expansion of the plume downwind will cause overlapping of the plumes and some combining of their odorants at a certain distance from their sources.

In the design and siting of a wastewater stabilization lagoon, it must first be determined if any odor emissions during periods of thermal turnover, overloading, after high algae growth, or when the ice cover which caused anaerobic conditions breaks up would cause an odor nuisance to adjacent residents. The odors are sometimes concentrated at the outfall, which is thus similar to a point odor source. This is particularly true if there is considerable turbulence in the treated effluent before it enters a receiving stream. Odor units emitted from several ponds under worst conditions and threshold odors can be determined by an odor panel for each pond. The threshold odor concentration of the most common odorants emitted from domestic wastewater varies from about 20 to 0.05 μg/l (with H_2S having a value of about 1 μg/l). Because of the unknown constituents of odors from wastewater, it is not practical for the designer to determine the concentration in micrograms per liter of the combination of odorants. For purposes of dispersion calculations, the odor units of an unknown odorant may be assumed equal to concentration in micrograms per liter.

For example, given that 1,000 odor units per cubic meter of air are emitted per cubic meter of wastewater discharged at the outfall. The maximum allowable threshold odorant concentration is 1 odor unit per cubic meter, and the stability conditions most apt to cause a problem occur with a wind velocity of 3 m/sec (7 mph). How far downwind would a threshold odor be detectable?

Based on Eq. 3-1:

$$\sigma_y \sigma_z = \frac{Q}{\pi u \xi} = \frac{1{,}000}{\pi (3)(1.0)} = 106$$

Utilizing Fig. 3-7, it can be found from curve F that, when $\sigma_y \sigma_z = 106$, the maximum distance downwind that the odor could be detected would be about 1,200 ft (400 m). A safety factor should be used by the designer, depending on the effect of stronger than expected maximum odors.

AREA ODOR SOURCES. Odors may rise from areas such as trickling filters, sludge beds, wastewater or sludge lagoons, wastewater or sludge processing tanks, etc., rather than point sources. Odor rise depends on vertical air temperature profile; movement of the odor horizontally depends on wind. The most probable conditions for odor problems is at the end of a long hot holiday weekend in the summer when maintenance is at a minimum. Because the most stable conditions must exist for detectable odors to be transmitted the maximum distance, tests made on existing wastewater facilities should be made on a clear but humid night or early morning while the night inversion conditions still continue and a mild, steady breeze is blowing. Under such conditions, a cross-section immediately downwind of the facilities can be sampled to define the variations in odor concentration across the plume. Under inversion conditions, the odors normally do not rise into the breeze at as high a rate as they do under temperature lapse conditions. Therefore, tests should ideally be run under both temperature lapse and inversion atmospheric thermal conditions.

CASE STUDY. A comprehensive study of possible odor problems arising from area sources and the possible resulting effects on neighboring urban and suburban developments is contained

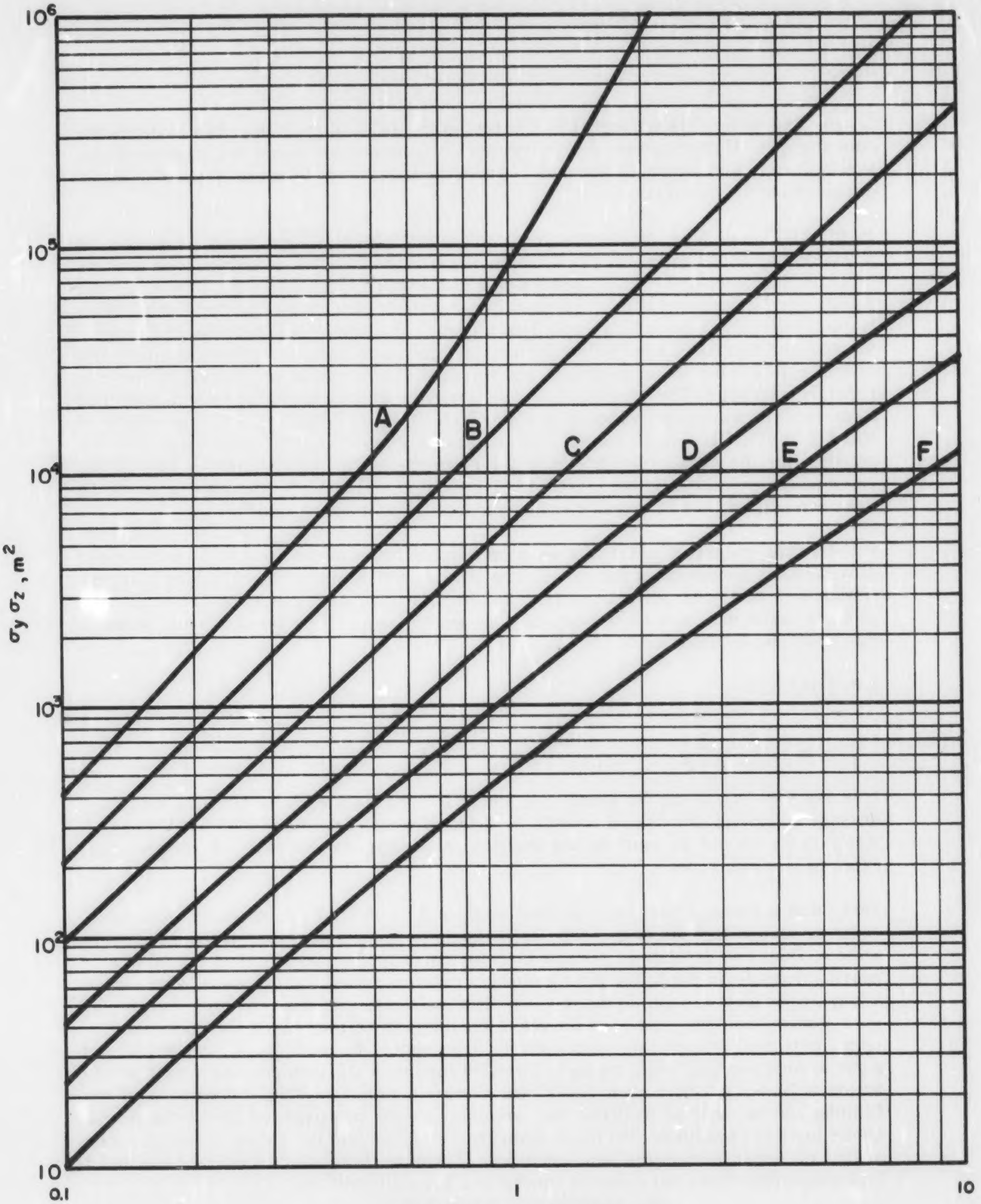


FIG. 3-7. THE PRODUCT OF $\sigma_y \sigma_z$

in reference *(31)*. This study was based on odors detected from an inadequately maintained, overloaded plant. It was assumed that the new plant, if also poorly maintained, would emit the same concentration of odors per unit area of facility as the existing plant. Another approach would have been to determine the maximum probable odor intensities which might be expected from an operating plant designed and operated similarly to the new facility. The study of odor distribution includes locating threshold odor concentrations by distance downwind of the source. The magnitude of the source was computed using the diffusion theory to produce the observed concentration at the observed location under the stability and wind conditions existing during the test.

The existing nine aeration tanks (40 ft each in diameter) had a total area of 11,300 ft^2, which the authors assumed to be the equivalent of one 106-ft-diameter tank. The source width then becomes 106 ft (32.4 m). The effective source strength is that concentration which is just sufficient to produce a threshold odor at some critical point downwind.

Threshold odors were detected 1.9 miles (3 km) downwind one day and 1.4 miles (2.3 km) another day from the plant by making cross-traverses of the plume at successively greater distances from the source. Wind speed, solar radiation, and the temperature lapse rates were measured during sampling. Types B and E stability conditions, respectively, prevailed during the two tests conducted.

Utilizing the curves reproduced on Figs. 3-1 to 3-4, the effective source concentrations were found to be 156 odor units per cubic foot for the test conducted under E stability conditions and 800 odor units per cubic foot for the test conducted under B stability conditions.

From the two examples, it can be seen that major odor nuisances result when conditions at the wastewater surface cause vapor to rise and carry large concentrations of odorants into the wind. This study concluded that the superadiabatic conditions in the locality could produce an odor source over five times as strong as inversion conditions. From this it is easily deduced that atmospheric conditions are very important and quite difficult to predict. Therefore, the safety factor to be used in determining the distance an odorant will travel should be from 2 to 5, depending on the sensitivity of the neighboring population to wastewater facility odors.

3.3 AEROSOLS AND PARTICULATES

Aerosols are defined as suspensions of approximately microscopic, solid or liquid, particles dispersed in the atmosphere. Aerosols from treatment works are usually 5 to 10 microns or less in size.

Particulates are, in general, considered to be liquid or solid particles of any size dispersed in the air. Aerosols and particulates may be organic, inorganic, or a combination of both. Foams, mists, dusts, smog, fumes, and smoke are among the different forms of aerosols and particulates. Liquid aerosols are generated at wastewater treatment works when bubbles of air from wastewater or liquid sludge burst and discharge tiny droplets into the atmosphere. All aeration, ventilation, evaporation (cooling towers), spray irrigation, and stripping activities involving wastewater or sludge are potential sources of aerosols. Activated sludge, trickling filter, and aeration units—particularly those handling raw wastewater—are probably the major potential sources of pollutional aerosols. However, with the increasing demands for reuse of wastewater, cooling towers and scrubbing units might become a major source of air pollution. Treated (but not disinfected) wastewater is sometimes used in these towers for evaporational cooling or for stripping out volatile organics and inorganics. Pathogens and toxic or injurious organic and inorganic pollutants in the wastewater may be aerosolized.

According to research studies of aerosols from wastewater treatment works, viable coliforms have been found up to 0.8 mile from sources *(3, 4, 47, 48, 49)*. *E. coli* has an extremely short life span in aerosol form. However, coliform bacteria of the genus *Klebsiella*, all species of which are known pathogens, form a capsule which apparently protects this organism from desiccation while in flight *(50)*. Results of specific tests for *Klebsiella* have not been found. While certain calculations *(1)* have shown that *Klebsiella* inhalation is possible at the downwind edge of an aeration basin, no evidence has been found that aerosols have affected the health of either wastwater works operators or other persons.

Sludge incinerators should be designed in accordance with state and local policies and regulations. EPA has developed performance standards *(8)* for wastewater treatment plant sludge incinerators. These standards require that no air pollutant discharge be made which is:

1. in excess of 0.030 grain (weight measure of pollutant) per standard cubic foot of gas
2. of 10 percent opacity or greater, unless the presence of uncombined water is the only reason for failure to meet this requirement.

Further restrictions may be placed on municipal plants processing industrial wastewaters, to prevent release of specific metals, toxic organics, or radioactive substances in the flue gases.

The sludge incinerator should be designed and located with regard to prevailing wind direction. Aerosols and particulates can often be removed from stack emissions by either scrubbing or electrostatic precipitation. Other control measures include the use of afterburners, collectors, and filtration. Some heavy metals and SO_2 have been found in emissions from incinerators, and care must be taken to ensure that their control is adequate.

Aerosols may also be caused by construction operations. Examples of these and methods for their control are given below:

> *Clearing, grubbing, and stripping.* Control dust by water sprinkling and chemical treatment such as use of calcium chloride. Seeding may be effective. Light petroleum or bituminous surface treatment may be used.
>
> *Excavation, stockpiling earth, and embankment placement.* Control dust by water sprinkling and chemical treatment. Seeding may be effective. Light petroleum or bituminous surface treatment may be used.
>
> *Blasting, quarry drilling, and rock crushing.* Use coverings or enclosures, and restrict operations to low wind conditions.

Cement and aggregate handling operations at mixing plants. Enclose operations and restrict to the most suitable location given land use and prevailing wind.

Cement or lime in soil stabilization operations. Select equipment to contain dust within dispersing hopper and also to dispense cement or lime with minimum dust.

Haul road construction and maintenance. Control dust by water sprinkling and chemical treatment.

Sandblasting and gunite operations. Conduct operations in enclosed space, properly vented, to trap aerosols. Enclosure may be by temporary barriers.

Smoke from heaters during winter operations and from asphalt plant heaters. Select better fuels and heaters to ensure higher than 1,400° F temperature and essentially complete oxidation.

Paint spraying operations. Control hazards by proper venting of work spaces. Reduce aerosols by use of proper application techniques and properly maintained equipment. Specify alternative coatings or applications.

Smoke from burning cleared growth and scrap material. Use pit incineration to limit escape of particulates, especially if burning is permitted for debris disposal.

3.4 GASES

Explosive, toxic, noxious, lachrymose, and asphyxiating gases found at wastewater works include chlorine, methane, ammonia, hydrogen sulfide, carbon monoxide, and oxides of nitrogen, sulfur, and phosphorus. If there is a possibility that such a gas can escape from the works, or into work areas, in dangerous or nuisance concentrations, the knowledge might affect the use and development of adjacent land and the operation of the works. Therefore, it is of the utmost importance that all precautions be taken to prevent the escape of such gases in hazardous or nuisance concentrations. Such gases are usually a greater detriment within wastewater structures than in adjacent areas.

Of the gases (including those above) collected from wastewater works structures by ventilation systems, some could be unsafe or adversely affect the environment if discharged directly to the atmosphere. Consideration should be given to monitoring such ventilation discharges for objectionable gases. Consideration should also be given to providing standby means for neutralizing, stabilizing, or destroying gases which might have significant effects on the environment.

Permanent or standby controls for gases or aerosols include:

1. passage through incineration or high temperature boilers whose flues are equipped with fly ash controls
2. passage through chambers or towers where oxidizing agents such as ozone, permanganate, or hypochlorite are introduced
3. passage through activated carbon columns
4. passage through chambers, scrubbers, or towers where masking or neutralizing chemicals are added, depending on the gases present in significant amounts.

Additional design, operation, and maintenance criteria for control of gases at wastewater works are presented in WPCF Manual No. 1, *Safety in Wastewater Works (9).*

3.5 REFERENCES

1. Sorber, C.A. and Guter, K.J., "Health and Hygiene Aspects of Spray Irrigation," *American Journal of Public Health*, Vol. 65, No. 1 (January 1965).
2. Adams, A.P. and Spendlove, J.C., "Coliform Aerosols Emitted by Sewage Treatment Plants," *Science*, Vol. 169 (September 1970).
3. Ledbetter, J.O., "Air Pollution From Wastewater Treatment," *Water and Sewage Works*, 113 (2):43–45 (February 1966).
4. Ledbetter, J.O. and Bandall, C.W., "Bacterial Emissions From Activated Sludge Units," *Industrial Medicine and Surgery*, pp 130–133 (February 1965).
5. Thibodeaux, L.J. and Carter, N.J., *Coliform Emissions From Air/Water Contractors: A Preliminary Attempt To Establish Maximum Concentrations*, Paper Presented at 65th Annual Meeting, American Institute of Chemical Engineers (November 1972).
6. Danielson, J.A., *Air Pollution Engineering Manual*, National Center for Air Pollution Control, Cincinnati, Ohio, U.S. Government Printing Office, Washington, D.C. (1967).
7. Stern, A.C. (ed.), *Air Pollution*, Vols. I, II, III, Second Edition, Academic Press, New York (1968).
8. *Background Information for Proposed New Source Performance Standards*, U.S. EPA Office of Air Programs, Research Triangle Park, North Carolina (June 1972).
9. *Safety in Wastewater Works*, WPCF Manual of Practice No. 1 (1975).

11. *Sensory Evaluation of Materials and Products,* ASTM Standard E253-67 T (1974).

12. Bethea, R.M., Murphy, B.N., and Carey, D.R., "Odor Controls for Rendering Plants," *Environmental Science and Technology* (June 1973).

13. Poltorak, R.L., *Odor Pollution and Control of Sewage Treatment Facilities,* Calgon Corporation, Pittsburgh (April 1974).

13. Post, N., "Counteraction of Sewage Odors," *Sewage and Industrial Wastes,* Vol. 28, No. 2, pp 221–225 (February 1956).

15. Dague, R.R., "Fundamentals of Odor Control," *Journal WPCF,* Vol. 44, No. 4, pp 583–594 (April 1972).

16. *Atmospheres for Analyses of Gas and Vapors,* 1974 Annual ASTM Standards, Part 26, 0 1605-60 (1973).

17. Dean, J.A., *Langes Handbook of Chemistry,* McGraw-Hill, New York (1973).

18. *Process Design Manual for Sulfide Control in Sanitary Sewerage Systems,* U.S. EPA Office of Technology Transfer (October 1974).

19. *Design and Construction of Sanitary and Storm Sewers,* ASCE Manual of Practice No. 37, p 125 (1969).

20. Bhatla, M.N., "Control of Odors at an Activated Sludge Plant," *Journal WPCF,* Vol. 47, No. 2 (February 1975).

21. Rains, B.A. and DePrimo, M.J., *Odors Emitted From Raw and Digested Sewage Sludge,* Prepared for U.S. EPA Office of Research and Development, EPA-670/2-73-098 (December 1973).

22. Osag, T.R. and Crane, G.B., *Control of Odors From Inedibles-Rendering Plants,* Prepared for U.S. EPA Office of Air and Wastes Management (July 1974).

23. Newfeld, R.N., "Wastewater Treatment Plant Odors: A Continuing Enigma," *Public Works* (March 1975).

24. Jones, F.W., "What Are Offensive Odors About a Sewage Works?" *Sewage Works Journal,* Vol. 4, No. 1., pp 60–71 (January 1932).

25. Kremer, J.G., *Odor Control Methods, Experimentation and Application,* County Sanitation Districts of Los Angeles County, California (No Date).

26. Cohn, M.M., "Sewage Works Odors and Their Control," *Sewage Works Journal,* Vol. 1, No. 5, pp 568–577 (October 1929).

27. Beardsly, C.W., "Removal of Sewer Odors by Scrubbing With Alkaline Solution," *Sewage and Industrial Wastes,* Vol. 30, No. 2, pp 220–225 (February 1958).

28. Pomeroy, R. and Bowlus, F.D., "Progress Report of Sulfide Control Research," *Sewage Works Journal,* Vol. 18, No. 24, pp 597–640 (July 1946).

29. Schneider, W.A., "Sewer Maintenance Practice in Los Angeles," *Sewage and Industrial Wastes,* Vol. 26, No. 2, pp 222–229 (February 1954).

30. Sawyer, C.N. and Kahn, P.A., "Temperature Requirements for Odor Destruction in Sludge Incineration," *Journal WPCF,* Vol. 32, No. 12, pp 1274–1278 (December 1960).

31 Shepherd, J.A. and Shreve, E.C., Jr., *Odor Control With Hydrogen Peroxide,* WPCF Deeds and Data (April 1973).

32. Keller, P.J. and Cole, C.A., "H_2O_2 Controls Bulking," *Water and Wastes Engineering* (September 1973).

33. *Standard Methods for the Examination of Water and Wastewater,* APHA, AWWA, WPCF, American Public Health Association, Washington, D.C. (1971).

34. *Manual on Sensory Testing Methods,* ASTM Special Technical Publication No. 434 (1968).

35. *Measurement of Odor in Atmospheres,* ASTM D1391-57 (Reapproved 1967).

36. *Handbook for Analytical Quality Control in Water and Wastewater Laboratories,* U.S. EPA NERC Analytical Quality Control Laboratory for U.S. EPA Office of Technology Transfer (June 1972).

37. *Sampling Atmospheres for Analyses of Gases and Vapors,* ASTM D1605-60 (Reapproved 1973), Part 26 of Annual Book of ASTM Standards (1974).

38. *General Gas Chromatography Procedures,* ASTM E260-73, Part 42 of Annual Book of ASTM Standards (1973).

39. Shepherd, J.A. and Hobbs, M.F., "Control of Hydrogen Sulfide With Hydrogen Peroxide," *Water and Sewage Works* (August 1973).

40. Santry, I.W., Jr., "Hydrogen Sulfide Odor Control Measures," *Journal WPCF,* Vol. 38, No. 3, pp 459–463 (March 1966).

41. Unangst, P.C. and Nebel, C.A., "Ozone Treatment of Sewage Plant Odors," *Water and Sewage Works,* Reference No. 1971, Vol. 118, pp R-42,43 (31 August 1971).

42. Sax, I.L., *Dangerous Properties of Industrial Materials,* Reinhold, New York (1963).

43. Herr, E. and Poltorak, R.L., "Program Goal—No Plant Odors," *Water and Sewage Works* (October 1974).

44. Stone, R., Newton, L.C., and Rowlands, J., "Wastewater Pumping Station Designed To Avoid Odor Problems," *Public Works* (January 1975).

45. Carlson, D.A. and Leiser, C.P., "Soil Beds for Control of Sewage Odors," *Journal WPCF*, Vol. 38, No. 5, pp 829–840 (May 1966).

46. Turner, B.C., *Workbook of Atmospheric Dispersion Estimates*, U.S. EPA Office of Air Programs, NTIS PB 191482 (1970).

47. Adams, A.P. and Spendlove, J.C., "Coliform Aerosols Emitted by Sewage Treatment Plants," *Science*, Vol. 169, pp 1218–1220 (18 September 1970).

48. Nelson, R.Y. and Ledbetter, J.O., "Atmospheric Emissions From Oxidation Ponds," *Journal of the Air Pollution Control Federation*, Vol. 14, No. 2, pp 50–52 (February 1964).

49. Pomeroy, R.D., "Sanitary Sewer Design for Hydrogen Sulfide Control," *Public Works*, pp 93–96 (October 1970).

50. Randall, C.W. and Ledbetter, J.O., "Bacterial Air Pollution From Activated Sludge Units," *Am. Ind. Hyg. Assoc. J.*, 27:506–519 (1966).

51. Cross, F.L., *Air Pollution Odor Control Primer*, Technomic Publishing Co., Inc., Westport, Connecticut (1973).

52. *Standards of Performance for New Stationary Sources*, Federal Register, Vol. 39, No. 47, Part II, Subchapter C—Air Programs (8 March 1974).

53. *Design Manual for Small Wastewater Treatment Plants*, U.S. EPA Office of Technology Transfer (At Press).

54. Silvey, J.K.G., Abshire, R.L., and Nunez, W.J. III, "Bacteriology of Chlorinated and Unchlorinated Wastewater Effluents," *Journal WPCF*, Vol. 46, No. 9 (September 1974).

4. NOISE

4.1 GENERAL BACKGROUND

Wastewater facilities must be designed, constructed, operated, and maintained in such a manner that they do not produce excessive noise which would be an irritant to nearby inhabitants or a hazard to plant workers. Noise prevention and control measures are discussed in this chapter, as are noise level criteria. Noise analyses and examples of calculations of noise transmission are presented at the end of the chapter.

The purpose of this chapter is to enable the designer to make preliminary estimates of the reactions of the community and works' personnel to noise generated by wastewater treatment facilities and to quantify the amount of noise reduction required to meet level standards. If indicated by the preliminary studies, specialists in noise engineering should be consulted.

Excessive noise may adversely affect personnel in interior and exterior areas of the facility as well as the surrounding community. Noise effects on people may be classified into auditory, general psychological and sociological, and physiological effects *(1)(2)*. Auditory effects include ear damage, with resulting temporary or permanent hearing loss, and masking effects, such as interference with speech communication, inability to hear warning signals, etc. Psychological and sociological effects may include sleep loss, annoyance, disruption of activities, lowering of performance, mental stress, and anxiety. Physiological effects include such responses as tautness of skin and abnormal sensations in the extremities.

Evaluation of noise levels in a community is a complex problem, involving individual perception of how an objectionably noisy environment is defined. Definition of these perceptions is difficult and involves measurements of ambient noise levels in the area. People respond in a complex way to the sum of stimuli present in their environment. They may react differently to an identical sound under different circumstances but similarly to sounds which are dissimilar.

Maximum noise levels for working areas are defined by regulations authorized under the federal 1970 Occupational Safety and Health Act (OSHA) and by its predecessor, the Walsh-Healey Act *(3)(4)*. Acceptable levels for adequate speech communication in the working environment are available *(5)*. Community noise levels have been researched, and information exists on desirable noise levels *(6, 7, 2)*. Both maximum and desirable noise levels for working spaces as well as community noise levels are presented in the following sections.

Preceding page blank

4.2 UNITS OF EXPRESSION AND MEASUREMENT

Noise control techniques are determined by comparing noise source measurements (sound pressure level, source direction, sound direction, sound power, etc.) with a specified design goal or criterion for acceptable noise levels at a listener's position. Sound pressure is sensed by a microphone and amplified in a sound level meter for frequency analysis or display on a decibel meter *(8)*.

Decibels are logarithmic units for measuring the relative levels of various acoustical quantities *(9)* on a scale beginning with 0 for faintest audible sound and reaching 130, the approximate threshold of pain.

Sound power levels should not be confused with sound pressure levels, which are also expressed in decibels. Sound power level is related logarithmically to the total acoustic power radiated by a source. Sound pressure level specifies the acoustic *disturbance* produced at a point. Sound pressure level depends on the distance from the source, losses in the intervening air, room effects (if indoors), etc. Sound power level is analogous to the heat production of a furnace; sound pressure level is analogous to the temperature produced at a given point in the house.

Noise has four important attributes *(10)*:

1. *Sound pressure level and directivity characteristics.*

   Sound pressure level L_p = $10 \log(p^2/p^2_{ref})$

   where

   p = root-mean-square sound pressure in pascals (Pa) or newtons per square meter (N/m^2)

   p_{ref} = reference pressure at 2×10^{-5} Pa or 20 μPa*

2. *Intensity (sound power level), measured in decibels.*

   Intensity L_I = $10 \log(I/I_{ref})$

   where

   I = watts passing in a specified direction through a unit area

   I_{ref} = 1 picowatt** (pW)

NOTE: Manufacturers' data sometimes include sound power levels but seldom sound pressure level.

---

*1 micropascal (μPa) = 10^{-6} pascal (Pa) = 10^{-6} newton per square meter.

**1 picowatt (pW) = 10^{-12} watt (W).

3. *Duration and number of times a noise occurs.* Intermittent sound (a noise whose sound pressure level equals the ambient level for about 1 second twice or more during the observation period [*11*]) and impulsive sound (a noise characterized by brief excursions of a sound pressure of about 1 second which significantly exceeds the ambient sound [*11*]) are usually more disruptive than continuous noise.

4. *Frequency (the number of oscillations per second of a sine wave of sound expressed in hertz* [Hz]).* The human ear is more sensitive to high frequency sounds than low ones. Noise nuisance can occur over all or part of the audible range.

The threshold of hearing at 1 kilohertz (1 kHz or 10^3 Hz) for a young listener with acute hearing, measured under laboratory conditions, was determined to be at a sound pressure of 20 micropascals (20 μPa). This value was then selected as the reference pressure for sound pressure level.

Because the human ear does not respond uniformly to all sound frequencies, and in view of the fact that single-number descriptions of noise levels are often more convenient, decibel measurements are made using frequency weighting scales. The sound level meter (SLM) contains a weighting network which gives greater importance to sounds in a certain frequency range. A typical sound level meter contains four different response weighting networks, designated A, B, C, and D (International Electrotechnical Commission [IEC] Recommendations 123 and 179 and American National Standards Institute Standard S1.4-1971).

Fig. 4-1 shows the four weighting curves. The rationale for the weighting network is based on the fact that the apparent loudness attributed to sound varies with the sound pressure and its special content—the frequencies of the components of the sound. This effect is taken into account to some extent using the weighting networks. The A-, B-, and C-weighted scales discriminate against normal low, medium, or high frequencies, respectively (dBA, dBB, dBC) *(12)*. The D-weighted scale was developed for jet aircraft noise measurements. The A-weighted scale is commonly used in field measurements to better detect the higher frequencies to which the human ear is more sensitive. Weighted noise levels are increasingly used in codes and standards, because of the generally excellent correlation with observed human response to the many types of industrial and community noises.

The A-weighted sound level is measured directly with an A-weighting sound meter. There is a high degree of correlation among the A-weighted measurements of speech interference, loudness, and NC or PNC (see below) levels. A-weighted levels may be used to statistically describe varying noise levels; e.g., L_{90}, L_{50}, L_{10}, etc., would describe noise levels exceeded 90 percent, 50 percent, and 10 percent of the time, respectively.

Several rating procedures have been found useful for gaging human response to noise *(5)*:

1. *Noise criteria (NC) or preferred noise criteria (PNC) rating curves.* This method combines speech interference and loudness procedures to specify simultaneously the maximum permissible loudness level for a given space. The curves are used in rating noises in buildings (including air conditioning)—primarily in the design of offices such as those within treatment plants.

---

*1 hertz (Hz) = frequency measured in occurrences per second.

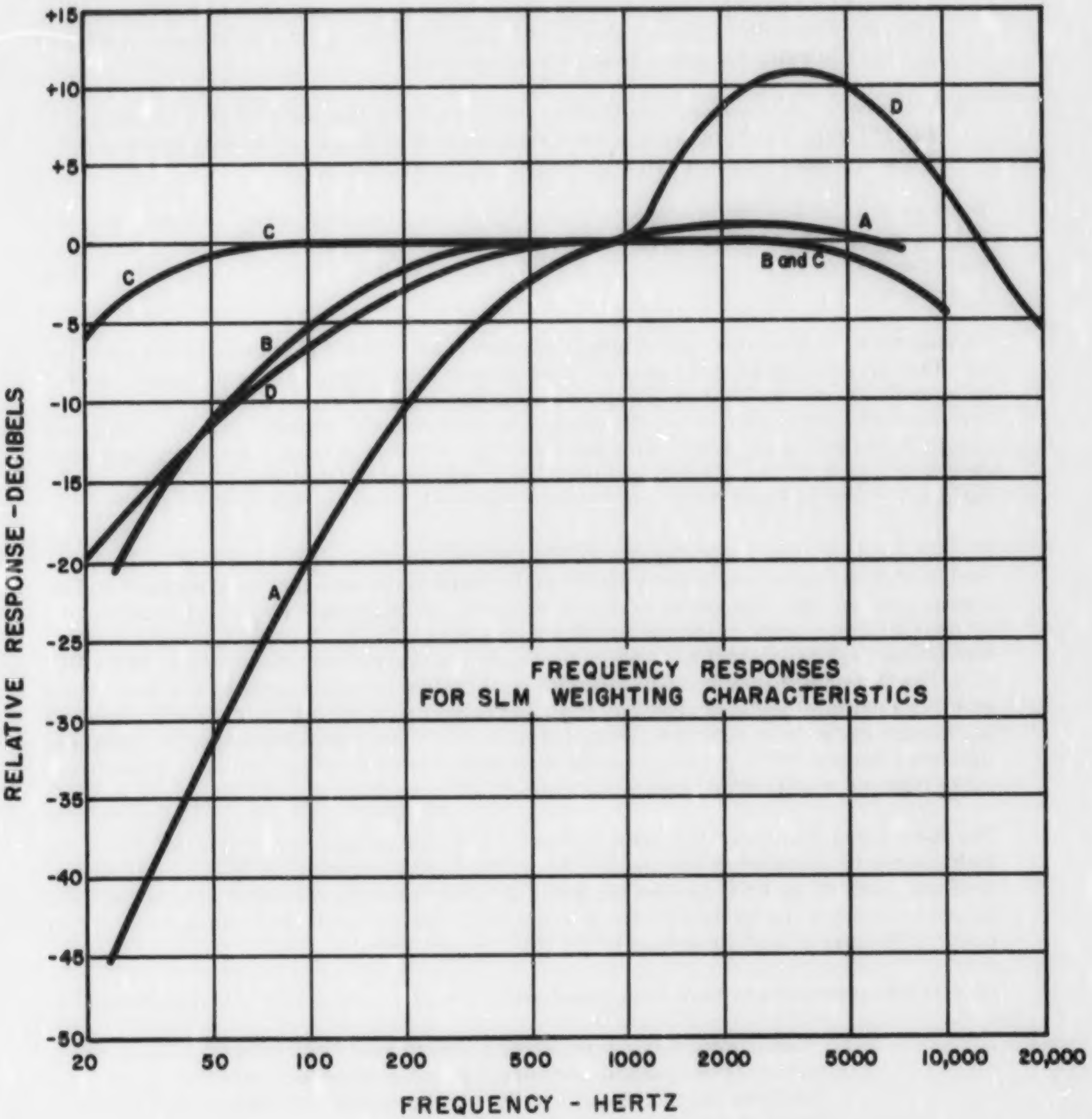


FIG. 4-1. FREQUENCY-RESPONSE CHARACTERISTICS

2. *Equivalent A-weighted sound pressure level (in decibels relative to 20 µPA) computed over any continuous 8-hour period identified with typical occupational exposure.* Equivalent sound level L_{eq} (8) is the time weighted, root-mean-square, A-weighted sound pressure which, in a given situation, has the same sound energy as does a time-varying sound. Because the magnitude of sound is of the utmost importance as far as cumulative noise effects are concerned, the long time average sound level is considered the best measure of the magnitude of environmental noise levels which cause damage to hearing *(2).*

3. *Equivalent A-weighted sound pressure level (in decibels relative to µPA) computed over a 24-hour period.* L_{eq} (24) is related to the cumulative noise exposure experienced by an individual irrespective of where, or under what circumstances, the exposure is received *(2).*

4. *A-weighted average sound pressure level (in decibels relative to 20µPA) during a 24-hour period, with a 10-dB weighting applied to nighttime sound levels.* L_d represents the equivalent sound pressure level for the 15-hour daytime period from 7:00 AM to 10:00 PM, and L_n represents the equivalent sound pressure level for the 9-hour nighttime period. The combined day/night weighted measure is represented by L_{dn}*(2).*

Computation of equivalent sound is presented in reference *(2)* and example 4-4.

4.3 TYPICAL NOISE LEVELS

Various organizations, including the EPA, have developed data on ambient and typical noise levels in the locations most frequented by people (Tables 4-1, 4-2, and 4-3).

4.4 ACCEPTABLE AND STANDARD NOISE LEVELS

Equivalent sound levels of different activities found by the EPA to be the maximum allowable while maintaining public health are listed in Table 4-4.

4.4.1 Allowable Exposure to Impact or Impulsive Noise

Occupational exposure to impact or impulsive noise, as ruled by OSHA, must not exceed 140 dB of peak sound pressure *(16).* It has been indicated by others that an increase of impulse durations above 1 microsecond, frequencies of about 3 kHz, or sound pressure levels above 130 dB will increase the probability of auditory damage *(2).*

Peak sound pressure levels should be measured with an instrument having a rise time of 50 microseconds or less (for square waves), which can calculate and display sound pressure levels

TABLE 4-1. EQUIVALENT SOUND LEVELS

Interior	L_{eq},* db
Small store (one to five clerks)	60
Large store (more than five clerks)	65
Small office (one to two desks)	58
Medium office (three to ten desks)	63
Large office (more than ten desks)	67
Miscellaneous business	63
Residences	
Typical movement of people—no TV or radio	40-45
Speech at 10 ft, normal voice	55
TV listening at 10 ft, no other activity	55-60
Stereo music	50-70

*Measurements were taken over durations typical of the operation of these facilities.

TABLE 4-2. ESTIMATED PERCENTAGE OF URBAN POPULATION (134 MILLION) RESIDING IN AREAS WITH VARIOUS DAY/NIGHT NOISE LEVELS(2)

Description	Typical Range L_{dn}, dB	Average L_{dn}, dB	Estimated Percentage of Urban Population	Average Census Tract Population Density, No. people/sq mi
Quiet suburban residential	48-52	50	12	630
Normal suburban residential	53-57	55	21	2,000
Urban residential	58-62	60	28	6,300
Noisy urban residential	63-67	65	19	20,000
Very noisy urban residential	68-72	70	7	63,000

TABLE 4-3. AVERAGE SINGLE NUMBER SOUND LEVELS, dBA (5, 13, 14, 15)

Interior noises	
Bedroom at night	30–40
Quiet residence	39–48
Residence with radio	47–59
Small office or store	47–59
Large store	51–63
Large office	57–68
Electric typewriter at 10 ft	62–67
Factory office	60–73
Automobile	64–78
Factory	65–93
School cafeteria	76–85
Railroad car	77–88
Garbage disposal	78–83
Airplane cabin	88–98
Noises 3 ft from source	
Whispering	30–35
Quiet ventilating outlet	41–47
Quiet talking	59–66
Noisy ventilating outlet	60–75
Business machine	71–86
Lathe	73–83
Shouting	74–80
Power saw	93–101
Power mower	94–102
Farm tractor	94–103
Power wood planer	97–108
Pneumatic riveter	110–120
Outside noises	
Leaves rustling	10–15
Bird call	40–45
Quiet residential street	40–52
150 to 200 ft from dense traffic	55–70
Edge of highway with dense traffic	70–85
Car at 65 mph at 25 ft	75–80
Propeller plane at 1,000 ft	75–84
Pneumatic drill at 50 ft	80–85
Noisy street	84–94
Under elevated train	88–97
Jet plane at 1,000 ft	100–105
Jet takeoff at 200 ft	120–125
50-hp siren at 100 ft	130–135

TABLE 4-4. YEARLY AVERAGE* EQUIVALENT SOUND LEVELS IDENTIFIED AS REQUISITE TO PROTECT PUBLIC HEALTH AND WELFARE WITH ADEQUATE MARGIN OF SAFETY (2)

(Based solely on health and welfare. Do not include considerations of Cost or Technology)

	Measure	Indoor			Outdoor		
		Activity Interference	Hearing Loss Consideration	To Protect Against Both Effects[1]	Activity Interference	Hearing Loss Consideration	To Protect Against Both Effects[1]
Residential, outside space and farm buildings	L_{dn}	45		45	55		55
	$L_{eq(24)}$		70			70	
Residential, no outside space	L_{dn}	45		45			
	$L_{eq(24)}$	70					
Commercial	$L_{eq(24)}$	[2]	70	70[3]	[2]	70	70[3]
Inside transportation	$L_{eq(24)}$	[2]	70	[2]			
Industrial	$L_{eq(24)}$[4]	[2]	70	70[3]	[2]	70	70[3]
Hospitals	L_{dn}	45		45	55		55
	$L_{eq(24)}$		70			70	
Educational	$L_{eq(24)}$	45		45	55		55
	$L_{eq(24)}$[4]	70				70	
Recreational areas	$L_{eq(24)}$	*(2)*	70	70[3]	[2]	70	70[3]
Farm land and general unpopulated land	$L_{eq(24)}$				[2]	70	70[3]

[1] Based on lowest level.

[2] Because different types of activities appear to be associated with different levels, identification of a maximum level for activity interference may be difficult, except in those circumstances where speech communication is a critical activity. Noise levels as a function of distance which allows satisfactory communication are presented in reference *(2)*.

[3] Based only on hearing loss.

[4] An $L_{eq(8)}$ of 75 dB may be identified in these situations, as long as the exposure over the remaining 16 hours per day is low enough to result in a negligible contribution to the 24-hour average; i.e., no greater than an L_{eq} of 60 dB.

*Refers to energy rather than arithmetic averages.

NOTE: The exposure period which results in hearing loss at the identified level is 40 years.
The levels cannot be construed as standards since they are based solely on health and welfare.

within 1 dB of true peak *(11)*. Typical peak sound pressure levels for impulse noises are given in Table 4-5.

Potential hearing impairment, which is a direct effect of noise, is of primary importance to a person who must work adjacent to the source of the noise. Workers should not be subjected to noise exposure levels exceeding those listed in Table 4-6.

The document *Information on Levels of Noise That Are Requisite To Protect Public Health and Welfare With an Adequate Margin of Safety*, prepared by the EPA Office of Noise Abatement, indicates that noise levels should be lowered to protect against the effects of occupational exposure. Accordingly, EPA has undertaken a critical evaluation of this subject and recommended the noise exposure levels listed in Table 4-6.

If the daily noise exposure comprises two or more periods of noise of different levels, their combined effect should be considered rather than the individual effect. Exposure to different levels for various periods of time is computed according to the formula:

$$F = T_1/L_1 + T_2/L_2 \ldots + T_n/L_n$$

where

F = equivalent noise exposure factor

T = period of noise exposure at any essentially constant level

L = duration of permissible noise exposure at constant level (from Table 4-6)

If the value of F is greater than unity, the mixed exposure must be considered to exceed the permissible exposure *(16)*.

4.4.2 Impulse Noises

The impulse noise limit to prevent more than a 5-dB permanent hearing loss at 4,000 Hz after years of daily exposure is a peak sound pressure level (SPL) of 145 dB *(2)*. However, for a duration of 25 microseconds or less, a peak level of 167 dB SPL would produce the same effect, as is shown in Fig. 4-2 (based on a study made by the NAS-NRC Committee on Hearing and Bio-Acoustics [CHABA]).

Fig. 4-2 shows a set of modified CHABA limits for daily exposure to impulse noises having B-duration (representing the duration of an impulsive sound, including the oscillatory noise decay time period) in the range 25 microseconds to 1 second *(2)*. (Parameter: number (N) of impulses per daily exposure; criterion: noise induced permanent threshold shift (NIPTS) not to exceed 5 dB at 4 kHz in more than 10 percent of the people.)

4.4.3 Community Noise Criteria

Description of community noise must take into account varying nuisance problems throughout a representative 24-hour period as well as seasonal fluctuations, if any. Noise is less tolerated at night in residential areas. Figure 4-7 can be used to judge the acceptability

TABLE 4-5. TYPICAL VALUES OF PEAK SOUND PRESSURE LEVELS FOR IMPULSE NOISE (2)

SPL	Example
190+	Within blast zone of exploding bomb
160-180	Within crew area of heavy artillery piece or naval gun when shooting
140-170	At shooter's ear when firing hand gun
125-160	At child's ear when detonating toy cap or firecracker
120-140	Metal to metal impacts in many industrial processes (e.g., drop forging, metal beating) adjacent to listener
110-130*	On construction site during pile driving adjacent to listener

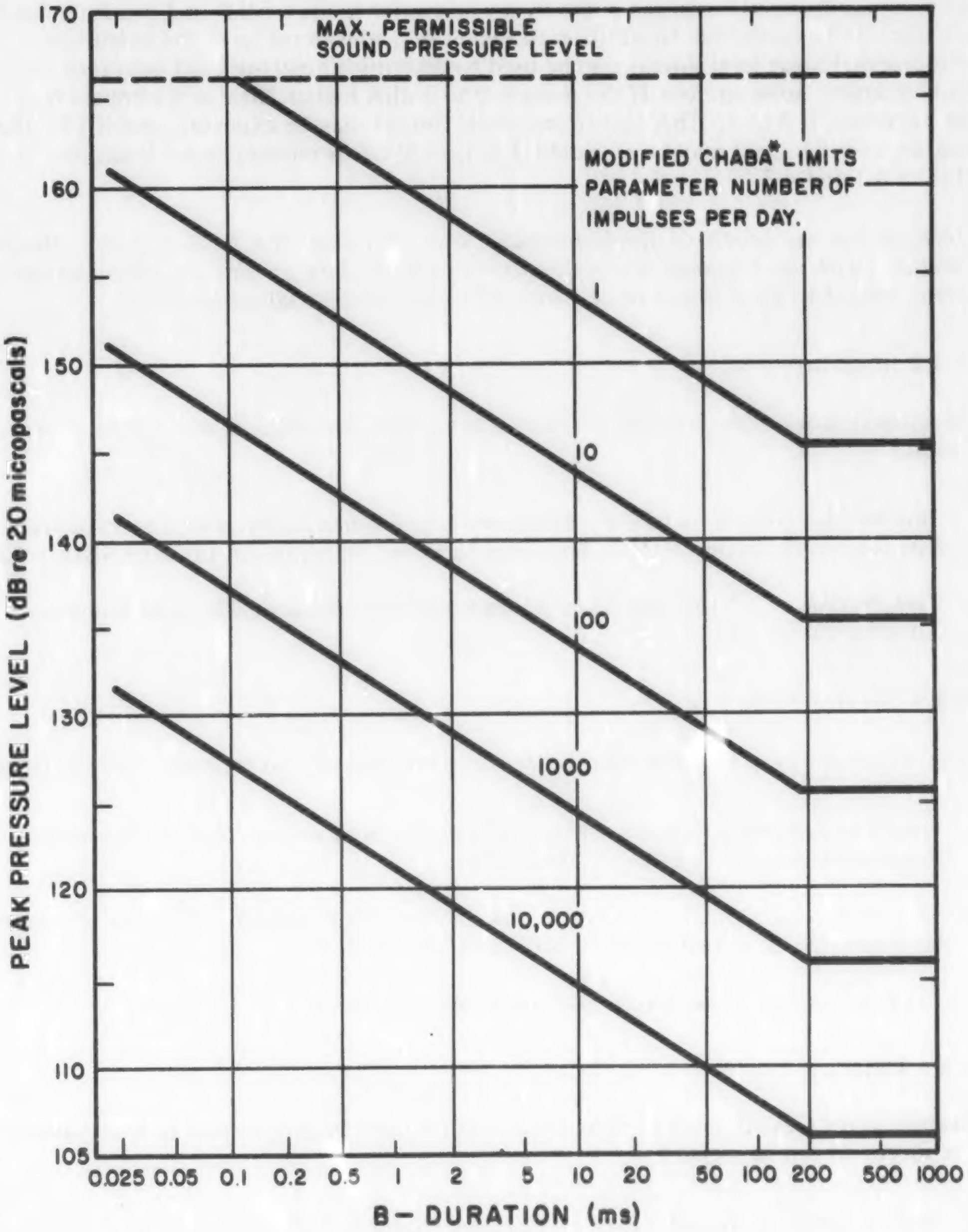
*These figures represent general ranges of SPL. The designer must obtain specific values from the manufacturer.

NOTE: All SPLs in db re 20 μPa.

TABLE 4-6. NOISE EXPOSURE LEVELS*

Duration, hours/day	Maximum Sound Level, dBA Slow Response	Recommended Sound Level, dBA Slow Response
8	85	75
4	88	78
2	91	81
1	94	84
0.50	97	87
0.25 or less	100	90

*Personal protective equipment should be supplied and used whenever reduction to the levels in column 3 of above table is not feasible.



* CHABA– COMMITTEE ON HEARING AND BIO-ACOUSTICS

FIG. 4-2. PEAK PERMISSIBLE SOUND PRESSURE LEVELS (2)

of community noise levels generated by a wastewater facility. State and local standards should also be consulted. In addition to Figure 4-7, consideration of the existing environmental noise level should also be used to determine neighborhood tolerance for new intensive noise sources. If the noise is 0 to 3 dBA higher, little or no impact may be expected; if 3 to 15 dBA higher, moderate impact may be expected; and if 15+ dBA higher, severe impact may be expected. For typical environmental noise levels, see Tables 4-1 and 4-3.

Information on Levels of Environmental Noise Requisite To Protect Public Health and Welfare With an Adequate Margin of Safety contains data on noise in industrial and traffic areas related to sleep interference, work efficiency, and social activities *(2)*.

4.4.4 Machinery Noise

Machinery noise measurement standards have been established, and the more important include:

> *Test for the Measurement of the Airborne Noise Emitted by Rotating Electrical Machinery*, ISO Recommendation R1680, American National Standards Institute (ANSI), 1970 *(18)*.
>
> *Test Procedure for Airborne Noise Measurements on Rotating Electrical Machinery*, IEEE No. 85 *(11)*.

4.4.5 Interior Noise

Interior noise measurement standards have been established, and the more important include:

> *Field and Laboratory Measurements of Airborne and Impact Sound Transmission*, ISO Recommendation R140, ANSI, 1960 *(20)*.
>
> *Acoustics: Assessment of Occupational Noise Exposure for Hearing Conservation Purposes*, ISO Recommendation R1999, ANSI, 1971 *(21)*.

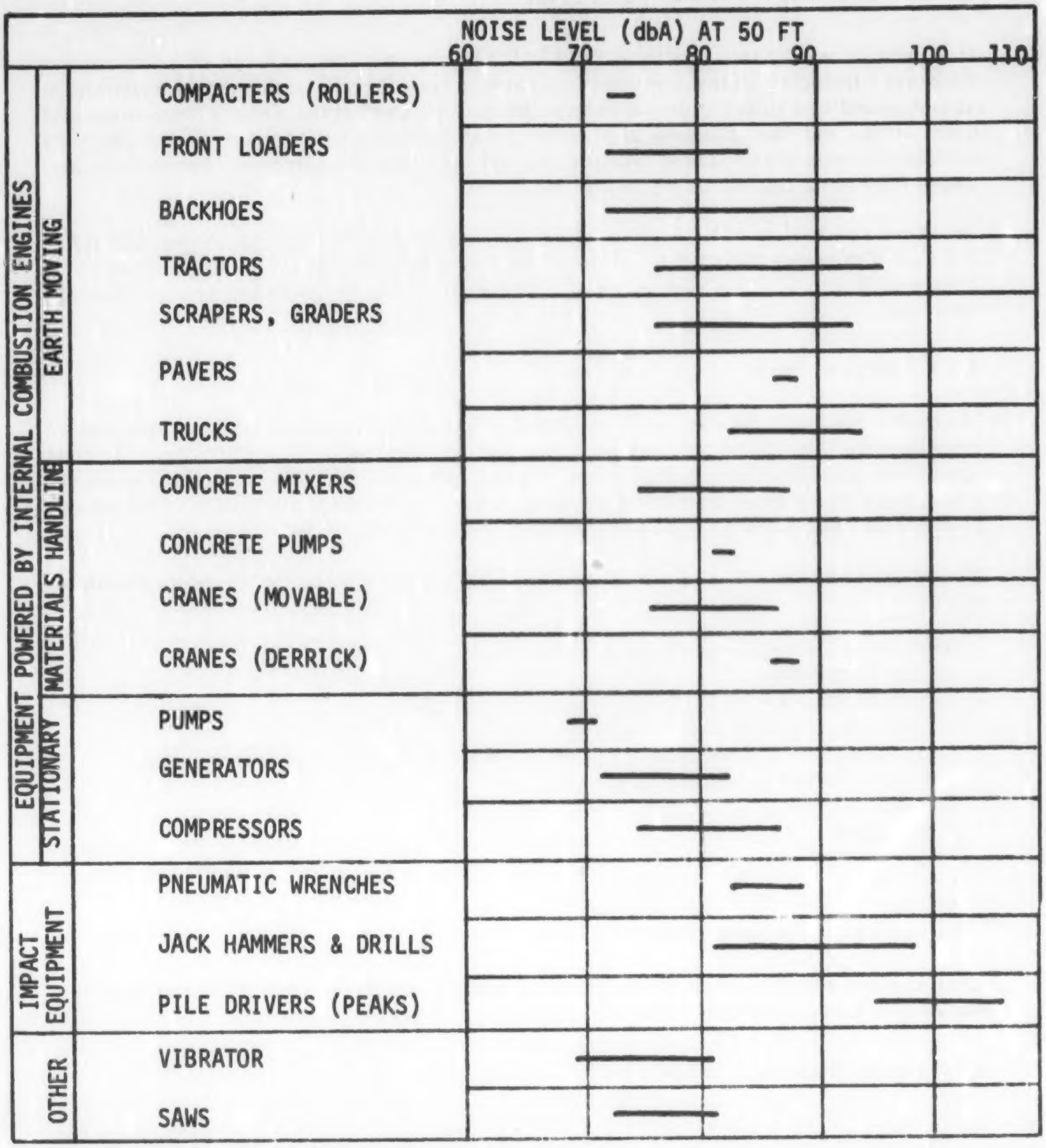
For normal interior noise levels, refer to Tables 4-1 and 4-3.

4.4.6 Exterior Noise

Standards for measurement of noise from construction equipment have been established, and the more important include:

> *Measurement of Sound Level at Operator Station for Agriculture and Construction Equipment*, SAI Recommended Practice J919a, 1971.
>
> *Sound Levels for Engine Powered Equipment*, SAE Standard J9526, 1969.

Ranges of noise levels in various urban areas are presented in Tables 4-2 and 4-3. Fig. 4-3 illustrates schematically construction equipment noise ranges.



NOTE: Based on limited available data samples.

FIG. 4-3. CONSTRUCTION EQUIPMENT NOISE RANGES (17)

4.5 NOISE CONTROL METHODS

Designers of wastewater treatment works should consider the inclusion of noise control measures—including source control of machinery noise, special architectural treatment to absorb sound and isolate noisy equipment, buffer zones within the plant between noisy and quiet areas, and site planning and buffer zones—to minimize impact of the plant on community noise levels. These measures should take into account both interior noise and community noise criteria, as discussed above.

The American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE, 345 East 47th Street, New York, NY 10017) publishes a handbook of fundamentals at 3-year intervals. *Sound Control Fundamentals*, chapter 6 in the 1972 edition, is a good design reference.

4.5.1 Source Control

Normally, noise can be most efficiently controlled at the source. A designer can control machinery noise by specifying the least noisy equipment consistent with performance. To meet acceptable acoustical levels, the designer should specify allowable sound power levels (or sound pressure levels at a specified distance) for the equipment, submission of laboratory and/or field measurements for approval, and field conformance tests.

The following techniques, singly or in combination *(10)(21)*, may be used to reduce machinery noise:

Segregation of noisiest elements in groups
Vibration damping
Vibration isolation
Sound absorbing line of enclosures
Sound attenuation at exhaust observation booth in auditory damage risk areas
Partial protective booths (open in rear)
Plenum treatment
Pipe lagging
Partial barrier
Lined ducts
Muffler
Reduction of high velocity air.

Gears can be a source of noise, unless the equipment is properly designed or the gear housing is placed in a sound-absorbing enclosure.

4.5.2 Piping Systems

Piping systems transmit noise through the fluid as well as along the pipe wall. To control noise, use flexible hangers and resilient connectors, do not connect drainpipes from vibrating equipment rigidly to building drains *(22)*, and use wrappings and duct linings where appropriate *(5)*.

Valve noise may be appreciable at pressure reducing valve stations. Control measures include commercial mufflers, enclosure, use of a diffractor to reduce turbulent flow *(22)*, reducing the throttling velocity, and adjusting the orifice diameter and valve trim *(23)*.

4.5.3 Mechanical Aerators

Noise from mechanical aerators consists of at least two components: noise from the equipment itself and splash noise. Pure tone whine could also occur from a noisy bearing. Because mechanical aerators are located in the open, they may be a potential noise nuisance to the community. Equipment selection should be based on an assessment of the community and the impact aerator noise will have on it. Control measures include proper maintenance to eliminate bearing noise, acoustically lined enclosure, or physical barrier surrounding the motor itself.

4.5.4 Compressors, Fans, and Blowers

Because of the intense, high pitched noise generated by this equipment, isolation in separate, acoustically insulated spaces is advisable. Mufflers may be placed on exhausts and/or intakes to control external noise. A plenum chamber may also be used to reduce external noise.

4.5.5 Vacuum Filter Pumps and Blowers

Noise from this source can best be controlled by isolating the pump in a separate room or on another floor from the filter equipment. Resilient pads and flexible piping connections will reduce transfer of vibration to the structure and piping system.

4.5.6 Pumps

Large pumps may generate noise exceeding the OSHA permissible noise limits. Control measures include sound absorbing enclosures and baffles.

4.5.7 Incinerators

Air inlet and exhaust noise from induced draft fan systems may be controlled by a plenum chamber or packaged attenuators.

4.5.8 HVAC

General control measures apply for most heating, ventilating, and air conditioning (HVAC) equipment. Ducts should be designed to reduce fan noise transmission as well as secondary noise generated by downstream air valves and other devices. Fresh air intake and exhaust grilles at the building exterior must be designed to avoid excessive noise transmission to the neighboring community. Pressurized oxygen generator units used in oxygen activated sludge treatment systems may require enclosure to reduce noise levels.

4.5.9 Architectural Noise Control

Architectural noise control is accomplished primarily by absorption and isolation. Interior noise levels in occupied spaces should not be allowed to exceed levels listed in Table 4-6. The more desirable 70-dBA design level will allow the speech and telephone communication necessary for safe operation. There are methods for determining noise levels in interior spaces, if machinery noise output is available from the manufacturer *(24) (25)*. If machinery noise output information is lacking, the designer may estimate likely noise levels, identify potentially noisy equipment based on experience, and design appropriate noise control measures.

NOISE CONTROL BY ABSORPTION. Absorption techniques can only minimize reflected noise (i.e., noise in the reverberant field of a room). Noise levels near equipment, usually within several feet, cannot be reduced by boundary surface treatment, because these levels are established by the sound emanating directly from the machinery.

Ceilings and walls may be lined with absorptive material, or absorptive baffles may be used if piping, ductwork, etc., precludes continuous application of acoustical treatment.

NOISE CONTROL BY ISOLATION. Noisy equipment can be isolated by impervious baffles or enclosures. Relatively heavy constructions such as sand-filled, concrete block walls are effective noise suppressants. Double door *sound lock* entryways may be used. Machinery can be isolated from the structure by special mountings and, in certain cases, by separate foundation pads.

4.5.10 Construction Noise Control

Noise during construction has an impact on the surrounding population. One study *(17)* estimates that 30 million Americans will find themselves living or working near a construction site each year.

Construction equipment, with built-in noise controls as well as operational management, may sufficiently control noise output to meet environmental noise requirements in most cases.

Noise may be measured at the borders of the construction site, to determine limits of maximum flexibility of operation onsite, while meeting noise standards offsite.

Design considerations to reduce equipment noise include: exhaust mufflers, intake silencers, engine enclosures, proper cooling system, and fan design. Table 4-7 lists basic information on sound levels associated with various types of construction equipment. Because these levels are average, actual noise levels will vary somewhat from those indicated. In particular, noise levels may be higher than those in the table for products within each category having a higher than average capacity. Level 1 in the table indicates current quiet products; level 2 lists equipment which can be quieted by the use of best demonstrated technology. Other techniques to be considered include: replacing individual operations and techniques by less noisy ones (e.g., using welding instead of riveting, mixing concrete offsite instead of onsite, and employing prefabricated structures instead of building them onsite) and selecting the quietest alternative items of equipment (e.g., electric instead of diesel-powered equipment, hydraulic tools instead of pneumatic impact tools).

Earth-moving equipment noises are associated predominantly with exhaust and inlet noise. Other sources include mechanical and hydraulic transmission and actuation systems and cooling fans. These usually result in noise levels at a 50-ft range of about 73 to 96 dBA (see Fig. 4-2). Mufflers offer the greatest potential for noise abatement. If possible, locate haul roads behind natural earth berms or embankments.

Most of the noise from materials handling equipment, such as cranes, concrete mixers, and concrete pumps, is generated by the engine. The greatest potential abatement is via engine quieting.

Where necessary, stationary equipment, such as pumps, generators, and compressors, can be quieted by mufflers and enclosures.

TABLE 4-7. BASIC INFORMATION ON CONSTRUCTION EQUIPMENT (1972)

Equipment Types	Present		Quiet Products Level 1		Best Technology Level 2		Units Produced per Year**
	Sound Level*	Average Unit Price	Sound Level*	Average Unit Price	Sound Level*	Average Unit Price	
Air compressor	81	$ 8,500	71	$ 9,500	65	$ 12,000	12,000
Backhoe	85	18,000	80	18,500	76	19,800	18,000
Concrete mixer	85	25,000	83	25,400	75	27,500	7,000
Concrete pump	82	50,000	80	50,650	75	55,000	500
Concrete vibrator	76	2,000	70	2,060	66	2,200	6,000
Crane, derrick	88	110,000	80	111,000	76	113,000	2,200
Crane, mobile	83	50,000	80	51,000	76	53,000	4,300
Dozer	87	28,000	83	28,800	78	30,800	18,000
Generator	78	1,000	71	1,100	65	1,400	70,000
Grader	85	22,000	80	22,600	76	24,200	7,000
Jackhammer	88	800	80	850	75	950	(20,000)***
Loader	84	20,000	80	20,600	76	22,000	30,000
Paver	89	42,000	80	43,000	76	44,200	800
Pile driver	101	33,000	90	33,500	80	37,000	350
Pneumatic tool	85	300	75	320	65	400	(100,000)
Pump	76	430	71	450	65	580	50,000
Rock drill	98	35,000	90	36,000	80	39,000	(1,000)
Roller	80	11,000	75	11,330	70	12,100	6,000
Saw	78	100	70	110	65	150	(500,000)
Scraper	88	70,000	83	71,500	78	75,000	5,000
Shovel	82	71,000	80	72,000	76	74,000	3,000
Truck	88	18,000	83	18,250	75	19,500	75,000

*Sound level refers to average level during operation in dBA at 50 ft.

**Estimated from Department of Commerce published data and industry sources (sales may include other industries).

***Parentheses enclose preliminary estimate.

Source: BBN Report No. 2887, 27 November 1974, *Regulation of Construction Activity Noise* (Table S1).

Impact tools include pile drivers, pavement breakers, jackhammers, and rock drills. Pile driver noise emanates predominately from the hammer hitting the pile (vibratory or *sonic* drivers eliminate this source). If necessary, holes may be drilled to bedrock and reinforced concrete piles may be poured in place to lower unsatisfactory pile driver noise levels. Noise from pneumatic jackhammers, pavement breakers, and rock drills comes from the exhaust and from the bit against the work. Exhaust can be muffled. A jacket will reduce internal tool noise.

4.5.11 Operational Noise Control

The following techniques could be utilized to reduce operational noise:

Using low noise emission equipment

Scheduling equipment operations to keep average noise levels low (e.g., scheduling the noisiest operation to coincide with times of highest ambient levels, keeping noise levels relatively uniform in time and turning off idling equipment, restricting working hours)

Increasing the number of machines at work at any one time to reduce the duration of noise exposure (this will increase the noise level during that time of operation)

Making use of speed limits to control noise from vehicles

Keeping noisy equipment operations as far as possible from site boundaries

Providing enclosures or sound shield skins for stationary items of equipment and barriers around particularly noisy areas on the site or around the entire site

Maintaining noise control devices.

The techniques for computing noise levels adjacent to the works are presented later in this chapter.

Noise control measures will be effective only as long as control devices are properly maintained. Mufflers need to be replaced before breakdown. Engine compartment enclosures and insulation may warp or bend. Large enclosures surrounding work areas may be breached and holed during operations and should be promptly repaired.

4.6 ACOUSTICAL COMPUTATIONS

Although special training and experience may occasionally be required, many of the noise problems encountered in wastewater treatment works design, construction, and operation are readily solvable. Reference *(5)* is particularly useful in this regard. In addition, the basic computations described in the following paragraphs are frequently encountered in determining the extent of acoustical problems present as well as in developing solutions.

4.6.1 Addition of Decibels

Often, the total contribution of more than one sound source must be considered. Because decibels are logarithmic units, their summation is not algebraic. Table 4-8 illustrates a simplified method for adding decibels.

4.6.2 Sound Power Level/Pressure Level Conversions

As stated earlier, sound power is a measure of the total acoustic power radiated by a source independent of its acoustic environment. Sound power level is the source power, expressed in decibels, relative to the reference power quantity 1 pW.* Ideally, specifications for the allowable noise output of equipment should be written in terms of sound power levels over the audible frequency range, usually in octave bands of frequency. Many manufacturers have sound power level data available for their equipment. Sound pressure levels (L_p) are those actually measured by a noise meter in a particular acoustical environment and are expressed in decibels relative to a standard reference pressure of 20 μPa.

The following represents an approximate method for converting sound power level data to sound pressure levels in outdoor situations (i.e., no nearby reflections except the ground or roof surfaces on which the source is located).

$$(L_p)\ \text{avg} = L_w - C$$

where

L_w = sound power level of the source in dB re 1 pW

(L_p)avg = average sound pressure level in dB re 20 μPa in specified frequency band

C = correction term in dB depending on type of source; for an omnidirectional source outdoors, assuming hemispherical spreading of sound, C is a function of the distance d in feet from the source given by:

$$C = 10 \log(2\pi d^2) - 5$$

The correction term C, for an omnidirectional noise source outdoors, is to be used to estimate sound pressure levels for distances of less than 100 ft (for typical wastewater treatment works noise sources, conversions of sound power levels to sound pressure levels should be made to some convenient distance from the source; e.g., 25 or 50 ft [see Table 4-9]). Further reduction in sound pressure levels beyond that specified distance would be computed by the procedure described in the section *Reduction of Sound Pressure Level With Distance Outdoors*.

---

*1 pW is the reference power used in this report and is the currently accepted power reference. When dealing with sound power levels, the reference must always be stated. Some acoustics literature uses 0.1 pW reference power. Sound power levels in dB re 0.1 pW may be converted to dB re 1 pW by reducing the numerical value by 10; e.g., 110 dB re 0.1 pW equals 100 dB re 1 pW (pW = 10^{-12} watt = 1 picowatt).

TABLE 4-8. ADDITION OF DECIBELS

Difference Between Two Decibel Quantities	Decibels To Be Added to Higher Value To Yield Sum
0 to 1 dB	3
2 or 3 dB	2
4 to 8 dB	1
9 dB or more	0

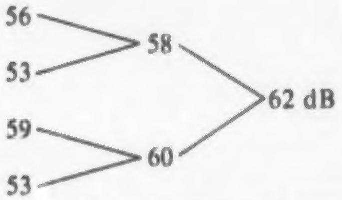


TABLE 4-9. C VALUES FOR OMNIDIRECTIONAL NOISE SOURCES*

Distance to Acoustic Center of Source, ft	C in dB for L_w re 1 pW
5	12
10	18
15	22
20	24
25	26
30	28
35	29
40	30
45	31
50	32
55	33
60	34
70	35
80	36
90	37
100	38

*$C = 10 \log(2\pi d^2) - 5$

Example 4-1

Given the sound power level of 110 dB re 1 pW in the octave band center frequency of 1 kHz (from manufacturer's data). Determine the average sound pressure level at 1 kHz and 25 ft from the geometric center of the source:

$$\begin{aligned} L_p &= L_w - C \\ &= 110 - 26 \\ &= 84 \text{ dB re } 20\ \mu\text{Pa} \end{aligned}$$

Similar computations of average sound pressure levels may be made at other frequency bands of interest. The values in individual octave bands may be added to yield overall sound pressure levels by the procedure described earlier in this section and in Table 4-8. Alternatively, the individual values may be corrected by appropriate frequency weighting values and then summed to yield an A-weighted sound level in dBA (See section 4.6.4).

Many noise sources, such as motor exhausts, are not omnidirectional—they radiate sound energy more efficiently in certain directions from the source. Thus the directional characteristics as well as the sound power of the source must be known to perform sound power level to sound pressure level conversions. The directivity index in a given direction from a sound source is the difference in decibels between (a) the sound pressure level produced by the source in that direction and (b) the space average sound pressure level of that source, measured at the same distance. Data on directivity for various mechanical equipment noise sources are usually available from the manufacturer, along with the equipment sound power level data, or may be estimated using the procedures of references *(26)(27)*.

In rooms, sound energy is not dissipated with distance because of the effect of room boundaries in establishing relatively constant reverberant field sound pressure levels, usually within several feet from the source. The correction terms for indoor conditions will vary with the average absorptivity of the room surfaces (see references *26* and *27*).

4.6.3 Reduction of Sound Pressure Level With Distance Outdoors

When the sound pressure level at a specified distance (d_1) from a noise source is known, a first approximation of the sound pressure level at a greater distance (d_2) from the source can be made by subtracting a distance correction term from the known sound pressure level. For a simple omnidirectional source outdoors, the distance correction term is given by $20 \log(d_1/d_2)$. More complete engineering calculations would include additional losses from air absorption, atmospheric attenuation, line of sight obstructions between the source and receiver, and other effects.

Example 4-2

The sound pressure level 50 ft from a noise source is 70 dB re 20 μPa. What is the sound pressure level 100 ft from the source?

Distance correction term:

$$20 \log(100/50) = 20 \log 2 = 6 \text{ dB}$$

at 100 ft

$$L_p = 70 - 6 = 64 \text{ dB re } 20\ \mu\text{Pa}$$

4.6.4 Conversion of Octave Band Sound Pressure Levels to A-Scale Sound Pressure Levels

Sound levels, as measured with a simple sound level meter using A-scale frequency weighting network, are often used in noise ordinances and codes, because they correlate well with human reaction to many types of sounds. Table 4-10 can be used to convert octave band sound pressure levels to A-weighted sound pressure levels when the latter cannot be measured directly **(see also Fig. 4-4 and example 4-5).**

4.6.5 Calculation of Effective Sound Isolation of Composite Barrier Construction (Interior Noise)

When a building exterior wall is made up of more than one component with different sound transmission loss (TL) characteristics, the effective sound transmission loss of the composite construction may be calculated using Figs. 4-5 and 4-6 and Table 4-11. The following parameters are used in Fig. 4-5:

T_1 = TL of basic acoustic barrier (wall)

T_2 = TL of secondary barrier element (window, door, crack, hole, or other sound leaks) located in basic acoustic barrier.

K = Percentage of total barrier areas of secondary element with respect to basic barrier.

D = Difference in TL of basic and composite barriers = $T_1 - T_0$

TABLE 4-10. RELATION BETWEEN OCTAVE BAND CENTER FREQUENCY AND A-SCALE FREQUENCY (5)

Octave Band SPL Center Frequency, Hz	Relative Response in dB re 20 μPa for A-Scale SPL Frequency Weighting Network
31.5	-39.4
63	-26.2
125	-16.1
250	-8.6
500	-3.2
1,000	0
2,000	+1.2
4,000	+1.0
8,000	-1.1
16,000	-6.6

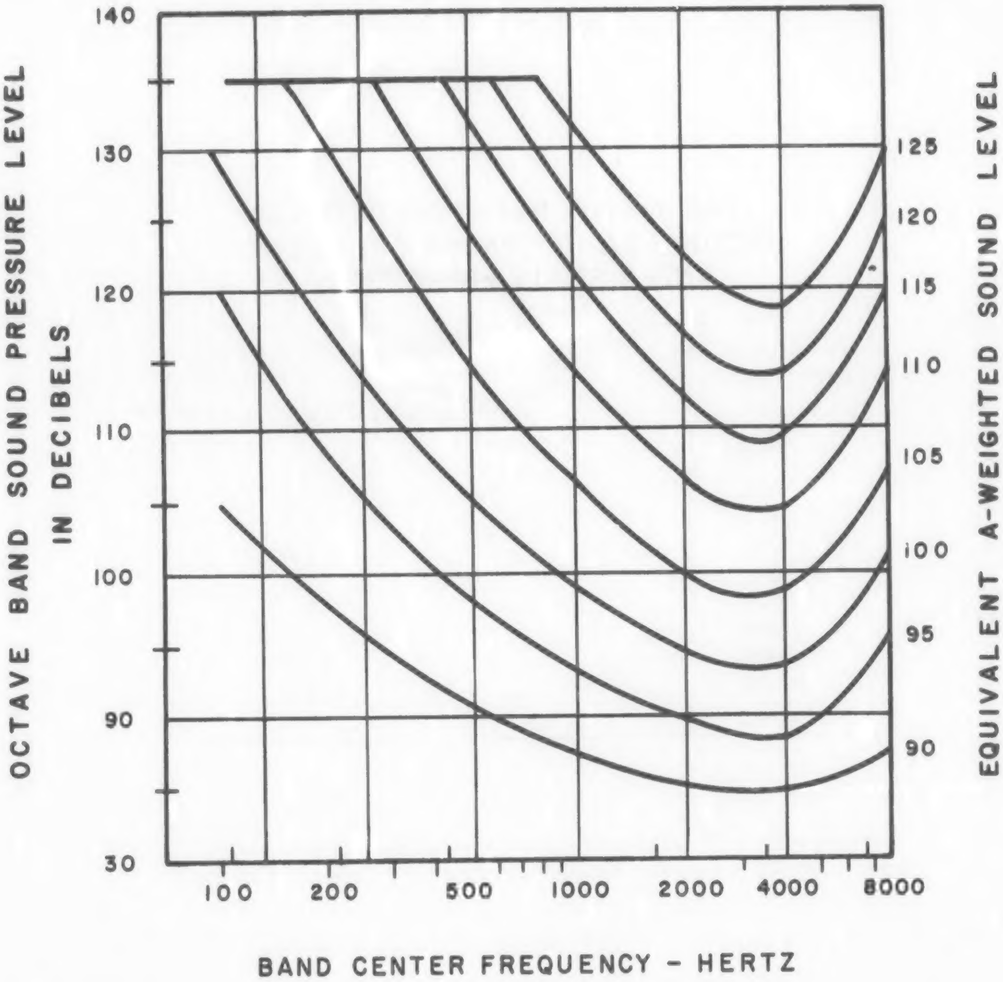


FIG. 4-4. SOUND LEVEL CONVERSION CHART

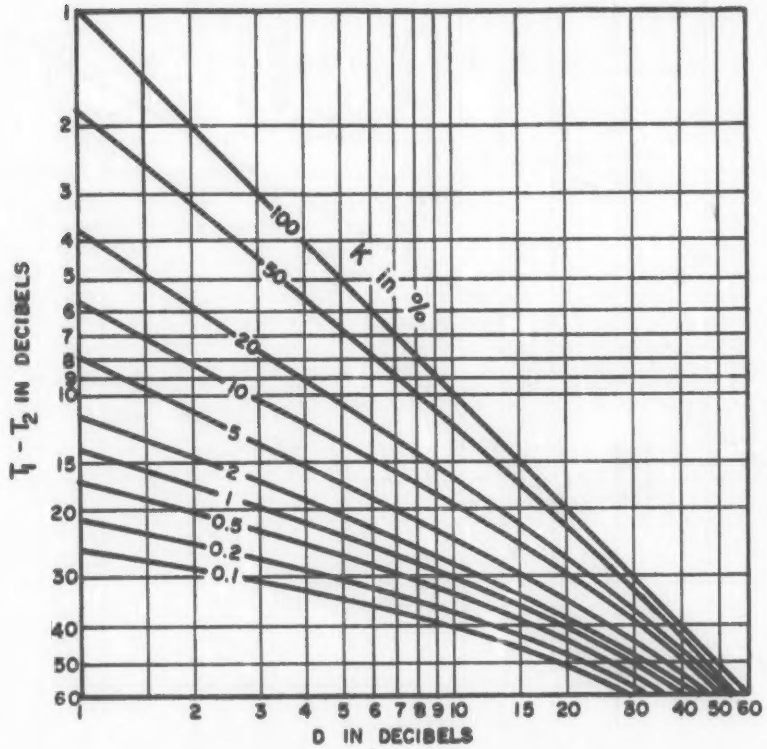


FIG. 4-5. EFFECTIVE TRANSMISSION LOSS (TL) OF COMPOSITE ACOUSTIC BARRIERS (14)

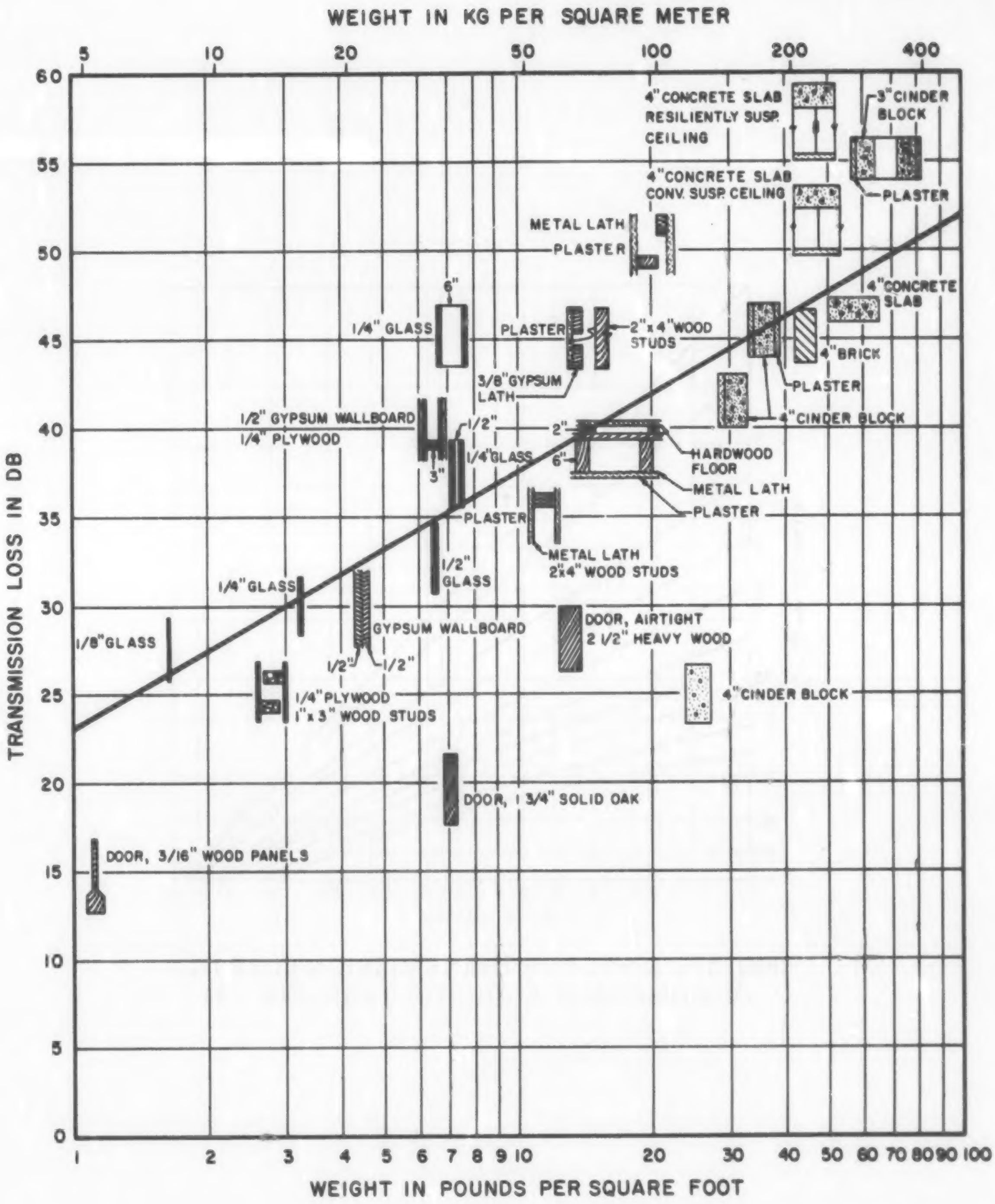


FIG. 4-6. TRANSMISSION OF NOISE THROUGH WALLS AND FLOORS (27)

TABLE 4-11. AIRBORNE SOUND TRANSMISSION LOSS VALUES FOR SOME COMMON BUILDING CONSTRUCTIONS DERIVED FROM FIELD MEASUREMENTS (16)

	Transmission Loss (db) at Listed Frequencies, Hz						
Building Construction	125	250	500	1,000	2,000	4,000	
Single Wall							
2-in. solid gypsum perlite-aggregate plaster (10 lb/sq ft)	28	30	29	34	40	48	1*
2-in. solid gypsum sand-aggregate plaster (18 lb/sq ft)	31	32	33	38	45	53	1
4-in. hollow-core gypsum block 5/8-in. sand-aggregate plaster both sides (25 lb/sq ft)	30	31	33	39	42	46	1
6-in. hollow-core cinder block painted both sides (33 lb/sq ft)	29	31	36	40	46	52	1
6-in. hollow-core cinder block, 5/8-in. sand-aggregate plaster both sides (43 lb/sq ft)	36	33	38	45	50	56	1
4-1/2-in. solid brick, plastered both sides (45 lb/sq ft)	34	35	40	51	57	60	1
7-in. stone-aggregate concrete, plastered both sides (90 lb/sq ft)	44	42	52	58	66	70	1
2 × 4 wood studs, 1/2-in. gypsum board both sides (6 lb/sq ft)	20	30	36	41	43	42	2
2 × 4 wood studs, 1/2 in. sand-aggregate plaster on 3/8-in. gypsum lath both sides (16 lb/sq ft)	27	25	31	44	34	50	1
2-1/2-in. wire studs, 5/8-in. sand-aggregate plaster on metal lath both sides (19 lb/sq ft)	26	24	37	31	37	50	1
2-1/2 in. wire studs, 1/2-in. sand-aggregate plaster on 3/8-in. gypsum lath both sides (12 lb/sq ft)	26	32	41	45	38	52	1
Double Wall							
Two separated rows of 3/4-in. furring channels 2-3/4-in. on center, 5/8-in. sand-aggregate plaster on metal both sides (4-3/4-in. total thickness) (17 lb/sq ft)	29	35	44	43	46	55	1
2-1/2-in. wire studs, 1/2-in. sand-aggregate plaster on 3/8-in. gypsum lath on 1/2-in. resilient metal clips both sides (12 lb/sq ft)	30	37	43	48	43	60	1
Staggered 3-1/4-in. wire studs, 1/2-in. sand-aggregate plaster on 3/8-in. gypsum lath both sides (5-3/4-in. total thickness) (13 lb/sq ft)	34	39	44	49	48	60	1
4-in. hollow-core gypsum block, 5/8-in. sand-aggregate plaster one side, 1/2-in. sand-aggregate plaster on 3/8-in. gypsum lath on 7/8-in. resilient metal clips second side (26 lb/sq ft)	25	33	43	48	49	54	1
Two wythes of plastered 3-in. dense concrete, 3-in. airspace between (bridging in airspace and at edges) (85 lb/sq ft)	38	40	51	54	57	65	1
Two wythes of plastered 4-1/2-in. solid brick, 2-in. airspace between (sound-absorbing material in airspace—bridging at edges only) (90 lb/sq ft)	43	50	52	61	73	78	1
Two wythes of plastered 4-1/2-in. solid brick, 12-in. airspace between (wythes completely isolated) (90 lb/sq ft)	57	70	83	93	—	—	1
Floor, Ceiling							
Typical residential floor-ceiling wood finish; and subfloors on wood joists, gypsum lath and plaster below (about 15 lb/sq ft)	24	32	40	48	51	54	1
Concrete floor slab, 1/2-in. plaster finish coat below (about 45 lb/sq ft)	43	40	44	53	56	58	1
Wood floating floor of finish; and subfloors on 2 × 2 sleepers on 3/4-in. glass fiber blanket on concrete structural slab, 1/2-in. plaster finish coat below (about 50 lb/sq ft)	38	48	55	61	59	55	1
Door							
1-3/8-in. hollow-core wood door, normally hung	5	11	13	13	13	12	2
1-3/8-in. solid wood door, normally hung	10	13	17	18	17	15	2
1-3/8-in. solid wood door, fully gasketed	16	18	21	20	24	26	2
Specially constructed 2-5/8-in. wood door, full double gasketing	20	23	29	23	31	37	2
Two specially constructed 2-5/8-in. wood doors, each with full double gasketing, 12-in. airspace between, each door hung on independent wythe of double wall	31	47	43	48	57	66	2

---

*1. Beranek, L.L., (ed.). *Noise Reduction*, chap. 13. McGraw-Hill Book Company, Inc., New York (1960).

2. Bolt Beranek and Newman Inc., unpublished data.

Example 4-3

Given one window with TL = 20 dB inserted in a wall with TL = 40 dB. The window occupies 5 percent of the wall. What is the effective TL of the composite barrier?

$$T_1 - T_2 = 40 \text{ dB} - 20 \text{ dB} = 20 \text{ dB}$$

$$K = 5 \text{ percent}$$

from the chart

$$D = 7\text{dB}$$

$$T_0 = T_1 - D = 40 - 7 = 33 \text{ dB}$$

The composite wall will then act like a homogeneous wall having a TL = 33 dB.

4.6.6 Calculation of Sound Insulation From an Enclosed Room to Outside

When the sound pressure level in a room is known, the exterior sound pressure level may be estimated for the frequency bands of interest from the expression:

$$L_p \text{ outside} = L_p \text{ inside} - TL - 6$$

where

L_p outside = average sound pressure level just outside structure in question (in dB re 20 μPa)

TL = sound transmission loss of enclosing construction in dB (use procedure shown in Example 4-3 if construction is made up of more than one component)

Example 4-4

The average sound pressure level inside a filtrate building is 75 dB re 20 μPa in the 1-kHz octave band. The exterior construction of the filtrate building has a sound transmission loss of 30 dB at 1 kHz. What sound pressure levels would be expected at 1 kHz outside the building?

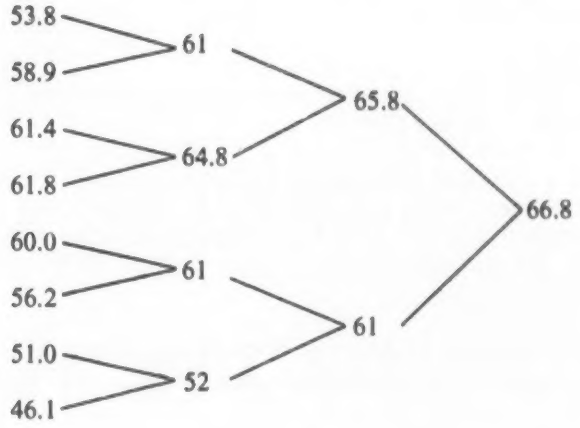
$$L_{p3} \text{ outside} = 75 - 30 - 6$$

$$= 39 \text{ dB re } 20\ \mu\text{Pa}$$

Example 4-5

Compute the equivalent A-scale sound level, given the octave band sound pressure level below:

Octave Band Center Frequency, Hz	Octave Band Sound Pressure Level, dB re 20 μPa	Relation A-Scale Response, dB	*Weighted* Octave Band Sound Pressure Level, dB re 20 μPa
63	80	-26.2	53.8
125	75	-16.1	58.9
250	70	-8.6	61.4
500	65	-3.2	61.8
1,000	60	0	60.0
2,000	55	+1.2	56.2
4,000	50	+1.0	51.0
8,000	45	-1.1	46.1



Sum of weighted octave band levels = 67 dBA.

4.6.7 Calculation of Noise Output From Plant Equipment

Generally, noise from fully enclosed, indoor equipment will not be significant. However, noise transmission through building walls should be checked, using control procedures described previously. Most significant wastewater treatment works noise will emanate from exterior mechanical aerators or from diffused air blowers housed indoors but with exposed inlets. The designer should obtain pertinent sound power and sound pressure level data from the manufacturer. For example, if blowers are to have only their inlets exposed, specific information on noise generated at the inlet should be obtained as well as overall noise generation data.

Noise from various equipment on the site should be summed using the methods described above. The noise level from an array of identical sources can be considered to emanate from the geometric center of the individual sources (e.g., a bank of mechanical aerators). If several sources are scattered throughout the site, they should be evaluated independently (e.g., separated banks of mechanical aerators, blowers, and other identifiable sources at the site).

4.6.8 Exterior Noise: Calculation of Total Noise Levels at Typical Locations on Periphery of Wastewater Treatment Works Property From All Significant Sources

This step is necessary, even if the land surrounding the wastewater treatment works is undeveloped, because future encroachment by residential and commercial construction may be possible. If noise levels are excessive at the periphery, it may be desirable to reduce noise emission from the equipment, acquire additional land, or zone for use compatible with high noise levels. In addition, noise levels at particular locations beyond the periphery of the facilities (e.g., at the nearest residences) should be estimated.

Finally, the estimated total noise generated by the treatment works should be compared with applicable codes or ordinances and EPA criteria The following examples and calculations are given as an aid to the design engineer.

Evaluation Method 1. Determine existing environmental (from all sources) noise levels at the site of adjacent land use:

1. By direct measurement and determination of L_{dn}
2. By use of Table 4-3 to determine an assumed existing noise level L_{dn}
3. Use the lower of the findings (1) or (2).

Determine probable reaction of adjacent land owners by comparing the estimated total noise from the wastewater treatment works at the site with existing noise levels at the site. If the noise from the wastewater treatment works is 0 to 3 dBA higher, little or no impact may be expected; if 3 to 15 dBA higher, moderate impact may be expected; if 15+ dBA or higher, severe impact may be expected.

Evaluation Method 2. Compare the estimated total noise levels from the wastewater treatment works with Figure 4-7 or existing State and Local Standards (whichever are more stringent).

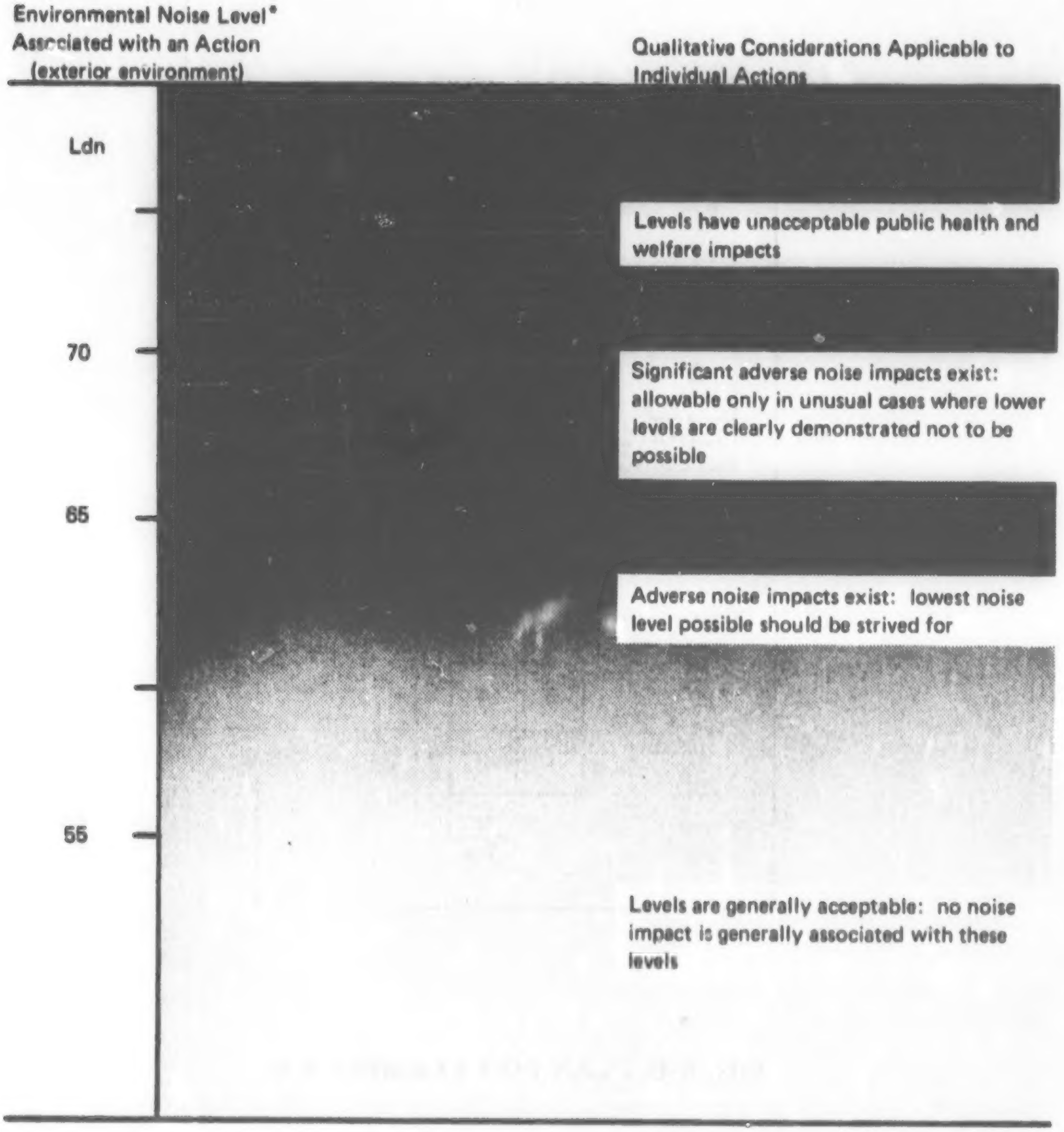
Example 4-6

Determine the relative impact on residence A as a result of the noise emanating from the treatment works. Given: locations as shown on Fig. 4-8.

NOISE SOURCES

Mechanical aerators	Each aerator produces 82 dBA, 10 ft from its geometric center (calculated from manufacturer's in-

Figure 4-7. Environmental Noise Levels for Residential, Hospital,and Educational Activity



*Some structures do not contain relevant exterior activity space and therefore, in these cases, special determination of the acceptability of the interior environment should be made.

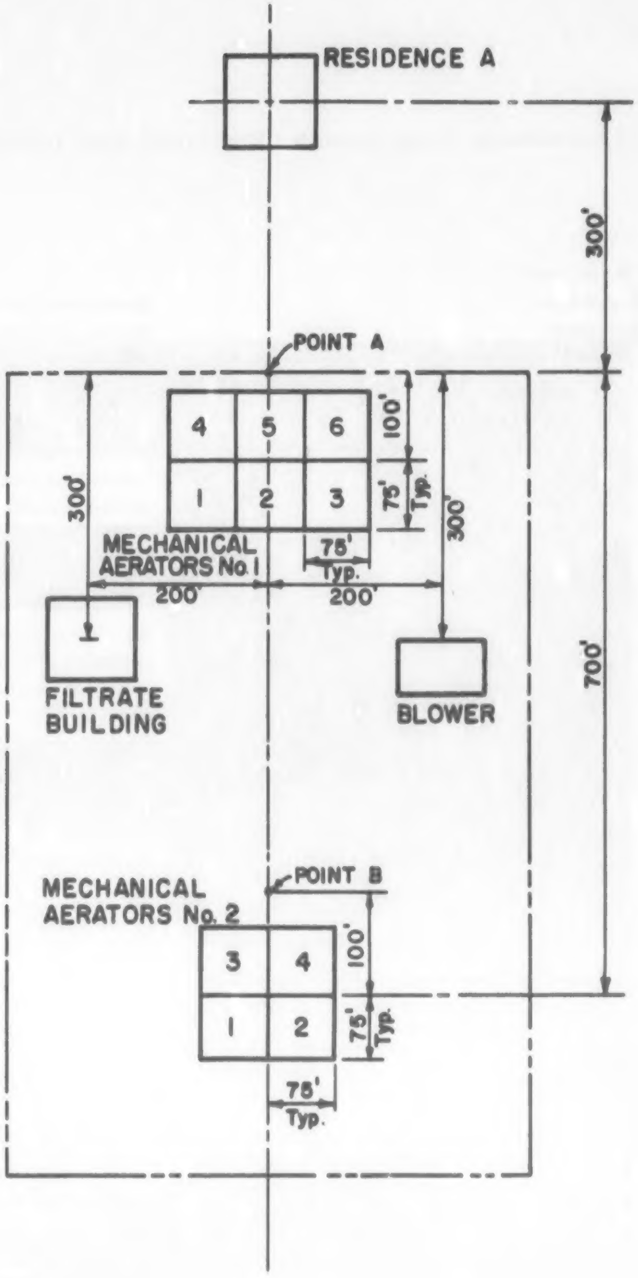

RESIDENCE A
300'
POINT A
4
5
6
1
2
3
100'
75' Typ.
300'
300'
MECHANICAL AERATORS No. 1
75' Typ.
200'
200'
FILTRATE BUILDING
BLOWER
700'
POINT B
MECHANICAL AERATORS No. 2
3
4
1
2
100'
75' Typ.
75' Typ.

FIG. 4-8. PLAN FOR EXAMPLE 4-6

	formation); aerator bank No. 1, six aerators at 82 dBA, aerator bank No. 2, four aerators at 82 dBA
Blower unit	70 dBA at 50 ft (from manufacturer's data)
Filter building	60 dBA at wall exterior, estimated from interior sound pressure levels and transmission loss through structure (assume source to be at center of building, 60-dBA noise level at exterior wall 50 ft from center)

MECHANICAL AERATOR BANK NO. 1. Convert given sound pressure levels (dBA) for individual aerators to a total sound level for the entire bank at an arbitrary point (point A) beyond the outer boundary of the bank (say, point A = 100 ft from the geometric center of the bank). The aggregate sound level at point A is then:

Aerators 1 & 3: $d = [(75)^2 + (137.5)^2]^{1/2} = 157$ ft

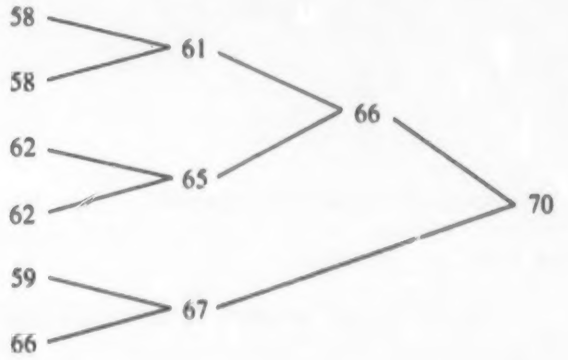
Reduction $= 20 \log 157/10 = 24$ dBA

$L_p = 82 - 24 = 58$ dBA

Aerator 2: $d = 137.5$ ft, $L_p = 82 - 23 = 59$ dBA

Aerators 4 & 6: $d = [(75)^2 + (62.5)^2]^{1/2} = 98$, $L_p = 82 - 20 = 62$ dBA

Aerator 5: $d = 62.5$ ft, $L_p = 82 - 16 = 66$ dBA



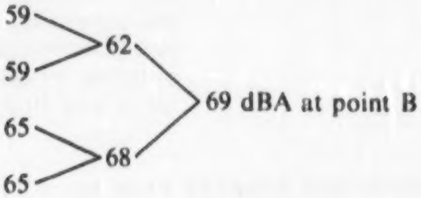
Distance correction: $20 \log (300 + 100)/100 = 12$ dBA

L_p at residence A $= 70 - 12 = 58$ dBA

MECHANICAL AERATOR BANK NO. 2. Sound pressure level at point B is:

Aerators 1 & 2: $d = [(137.5)^2 + (37.5)^2]^{1/2}$
$= 143$ ft, $L_p = 82 - 23 = 59$ dBA

Aerators 3 & 4: $d = [(62.5)^2 + (37.5)^2]^{1/2}$
$= 73$, $L_p = 82 - 17 = 65$ dBA



Distance correction $20 \log(1{,}000/100) = 20$ dBA

L_p at residence A $69 - 20 = 49$ dBA

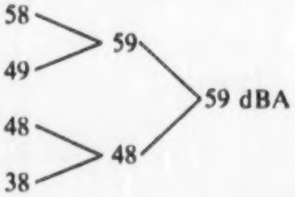
BLOWER. Distance correction
$20 \log [(200)^2 + (600)^2]^{1/2}/50 = 22$ dBA

L at residence A $70 - 22 = 48$ dBA

FILTRATE BUILDING. Distance correction: $20 \log [(200)^2 + (600)^2]^{1/2}/50 = 22$ dBA

L_p at residence A $60 \text{ dBA} - 22 = 38$ dBA

The total noise level at residence A from the wastewater works will be:



Determine probable impact on residential area as determined for nearest residence, house A. From Table 4-3, assume average nighttime suburban:

$50 \; L_{dn}$ = approximately 40 dBA nighttime

From method 1: $59 - 40 = 19$ dB difference, severe impact is expected to result. From method 2, the total noise level at

house A equals 59 dBA. Enter Figure 4-7 to determine that adverse noise impacts exist: lowest noise level possible should be strived for.

The result of this analysis is that sound reduction of one or more pieces of equipment is necessary. This preliminary analysis should be repeated for subsequent designs or alternative equipment selections. If the results of the final analysis still indicate adverse noise impact on the adjacent residential area, a comprehensive noise analysis should be undertaken to determine adequate noise abatement measures. The latter may include site layout changes to provide greater separation between the noisiest wastewater treatment works sources, provision of line-of-site barrier walls on earth berms at the property line, and noise attenuation of specific sources.

4.7 REFERENCES

1. *Effects of Noise on People*, U.S. Environmental Protection Agency, NTID 300.7, Government Printing Office 5500-0050, Washington, D.C., 1971.
2. *Information on Levels of Environmental Noise Requisite To Protect Public Health and Welfare With an Adequate Margin of Safety*, EPA 550/9-74-004, March 1974.
3. *Occupational Noise Exposure*, Occupational Safety and Health Administration, Federal Register, Vol. 36, No. 105, 1910.95, 29 May 1971.
4. Errata Published in Federal Register, Vol. 34, No. 96, 15 July 1969, Walsh-Healey Public Contracts Act; Federal Register, Vol. 34, No. 96, Rule 50-204.10, 20 May 1969.
5. Beranek, L.L., *Noise and Vibration Control*, McGraw-Hill Book Company, New York, 1971.
6. *Community Noise*, U.S. Environmental Protection Agency, NTID 300.3, Government Printing Office 5500-0041, Washington, D.C., 1971.
7. *Noise Assessment Guidelines*, U.S. Department of Housing and Urban Development, Government Printing Office 2300-1194, Washington, D.C., 1971.
8. Gately, W.S., "Industrial Noise Control," *Mechanical Engineering*, April 1971.
9. *Fundamentals of Noise: Measurement, Rating Schemes and Standards*, National Bureau of Standards, NTID 300-15, U.S. Government Printing Office, Washington, D.C., 1972.
10. Beranek, L.L., "Industrial Noise Control," *Chemical Engineering*, 27 April 1970.

11. *American National Standards Methods for the Measurement of Sound Pressure Levels*, American National Standards Institute, New York, 14 July 1971.

12. *Highway Noise: A Design Guide for Highway Engineers*, Highway Research Board, Report 117, Washington, D.C., 1971.

13. Peterson, Arnold P.G., and Gross, Jr., Ervin E., *Handbook of Noise Measurement*, General Radio Company, Concord, Massachusetts, 1972.

14. Newman, R.B. and Cavanaugh, W.J., *Acoustics*, Time Saver Standards, 4th Edition, McGraw-Hill, 1966.

15. Heer, J.E.; Hagerty, D.J.; and Paroni, J.L., "Noise in the Urban Environment," *Public Works*, October 1971.

16. *Occupational Noise Exposure*, Occupational Safety and Health Administration Rules and Regulations 1926.52, Federal Register, 16 December 1972.

17. *Noise From Construction Equipment and Operation, Building Equipment and Home Appliances*, U.S. Environmental Protection Agency, NTID 300.1, Government Printing Office 5500-0044, Washington, D.C., December 1971.

18. *Test for Measurement of the Airborne Noise Emitted by Rotating Electrical Machinery*, ISO Recommendation R 1680, ANSI, 1970.

19. *Field and Laboratory Measurements of Airborne and Impact Sound Transmission*, ISO Recommendation R 140, ANSI, 1960.

20. *Acoustics: Assessment of Occupational Noise Exposure for Hearing Conservation Purposes*, ISO Recommendation R1999, ANSI, 1971.

21. Seebold, J.G., *Process Plant Noise Control at the Design Engineering Stage*, Transactions of the American Society of Mechanical Engineers, Paper No. 70-Pet-11, 1970.

22. Yergas, L.F., *Sound, Noise and Vibration Control*, Van Nostrand Reinhold Company, New York, 1969.

23. *Noise From Industrial Plants*, U.S. Environmental Protection Agency, NTID 300.2, Government Printing Office 5500-0042, Washington, D.C., 1971.

24. *Power Plant Acoustics*, U.S. Army, TM 5-805-9, Headquarters, Department of the Army, Washington, D.C., 1970.

25. U.S. Army, *Noise Control for Mechanical Equipment*, TM, Headquarters, Department of the Army, Washington, D.C., 1970.

26. *Public Buildings Service Guide Specifications*, PBS: 4-0110 General Services Administration, Amendment 2, August 1972.

27. Harris, C., *Handbook of Noise Control*, McGraw-Hill Book Co., New York, 1957.

5. SITE PREPARATION, CONSTRUCTION, AND OPERATION PROBLEMS

This chapter addresses the many problems associated with site development and facility construction.

5.1 FLOODING AND DRAINAGE

The engineer must always consider problems which might result from flooding of the site or from flood runoff. EPA reliability guidelines specify the amount of protection against floods to be provided for wastewater treatment facilities *(1)*. Onsite flooding can be caused by inadequate flood protection measures; inadequate provisions for stormwater drainage from the site; or inadequate provisions for overflows of wastewater resulting from failure of equipment, stoppages of flow, or stormwater entering the wastewater system. Flood runoff from wastewater works sites might pollute both downstream land uses and waters receiving the runoff. To prevent interruption of operations by collection and treatment of such flooding, adequately protected standby facilities and equipment should be provided.

For flood plain analysis, refer to *Flood Hazard Evaluation Guidelines* published by the United States Water Resources Council, May 1972 *(2)*. Detailed evaluation criteria are included in this reference.

It is generally accepted in the courts that land cannot be modified in any way which will result in flooding, erosion, or additional damage to adjacent lands. Wastewater works are often constructed at low elevations or flood plains to take advantage of wastewater collection by gravity. In such cases, the design must allow floods to pass without significant restriction. Great care must be taken to ensure that existing natural drainage is not impaired and that runoff will not be impeded and result in flooding. This is particularly true in the design and construction of interceptors which cross natural drainage channels or shallow aquifers.

If the construction of a pond to store flood waters above a drainage culvert is possible, the culvert should be designed to restrict flows for maximum utilization of the available storage.

Flood runoff increases when the surface of an open area become more impervious because of construction of roads, parking areas, and structures. To prevent downstream flooding, downstream drainage channels must be sized to take the increased load or detention must be provided at the wastewater works site. Depressed parking areas which can store flood peaks and discharge the excess after rains have stopped are common practice. In other cases detention basins have been constructed by digging a 10- to 12-ft-deep basin, lining it, and filling it with crushed stone and gravel. Excess stormwater enters the rock-filled basin through a sedimentation basin and is pumped out after the storm has passed. Parking lots or other structures can be built on top of such detention basins.

5.2 SITE PREPARATION

Site clearing, grading, and excavating may generate such nuisances as dust, noise, erosion, and debris. Construction nuisances may be minimized by proper planning of construction operations. Working hours may be limited to reduce nuisances in the early morning and at night. Construction equipment must be selected for minimum noise and exhaust emissions. Weight and loading of vehicles should be kept below that causing damage to roadways, as determined by the governmental agency responsible for roadways. Construction operations should take into account adjacent land use. Permissible impact magnitudes will vary in importance according to the type of use.

Effective traffic control procedures might include provision to limit the length of an open trench. Stockpiling of excavated material could be limited to offsite locations only.

Construction sites, and particularly long rights-of-way, may include historical and archeological areas and remains. These cultural properties must be identified and protected in accordance with federal and state preservation programs. Impacts of federally assisted construction projects on cultural properties should be evaluated under procedures established by the Advisory Council on Historic Preservation (36 CFR 800). Cultural properties should be identified early in the project's planning stages, to avoid later construction delays which may result from mitigation activities to save affected properties.

If an archeological site is discovered during the construction process, project specifications could require that construction be halted to permit expert evaluation. For example, specifications could include a procedure to be followed in obtaining expert opinion, such as naming the expert to be employed, length of time construction may be halted without additional compensation to the contractor, and compensation to be paid for halting construction. In some cases it may be necessary to shift construction operations to another area of the project, to permit archeological excavation, or to relocate some portion of the proposed works.

It is desirable—and usually very important—to limit clearing to minimize erosion, reduce the visual impact of denuded landscape, preserve wildlife habitat, and (often) reduce total costs. An effective method of controlling clearing is to limit construction in an easement or right-of-way to a specified area or width not necessarily as large or wide as the easement or right-of-way. The required width for efficient construction depends on soil, depth of excavation, groundwater level, type of material utilized, method of construction, and equipment to be used. Because machine operators, who actually do the clearing, may not be informed of areas which must remain undisturbed, an effective control measure such as fencing or staking the area available for construction should be used. The method of construction may be specified to include use of particular types of equipment which reduce damage. For example, rubber-tired rather than tracked vehicles might be specified, to minimize damage to roads and sidewalks.

Trees may be protected by wrapping the trunks in protective covering and fencing them off. The root system may be safeguarded by limiting excavation and backfill within the dripline. If an impervious fill or surfacing covers 25 percent or more of the area under the branches of a tree, a tree well protecting the tree trunk and provision of a satisfactory method for irrigating the roots under the impervious fill or surfacing must be provided. Small trees may be removed with the root systems intact, burlapped, and set aside under carefully maintained conditions for use elsewhere on the site.

5.3 DISPOSAL OF CLEARING DEBRIS AND CONSTRUCTION WASTES

Disposal of material from construction operations is an increasing problem. Disposal sites, particularly in urban areas, are limited, and burning restrictions have created an increased demand for such sites.

Because of the complexity of the problem, detailed requirements for disposal of clearing and construction wastes should be included in contract documents. Such a plan might include expected types and quantities of waste, methods of transport, and methods of disposal, including identification of sites.

Construction wastes include:

wastes from equipment (fuel, oil, and grease)

wastewater from core drilling and foundation grouting operations

wastes from concrete operations
  aggregate washwater and screenings
  cement and concrete spillage
  concrete lift pump cleanup
  spillage and waste of curing compounds
  cleanup and washing of mixers and batch trucks

wastes from roads, camps, shops, and storage areas
  sanitary and other wastes
  spillage of fuels, grease, oil, etc.
  wastewater from equipment washing

wastes from asphalt operations
  spillage of bituminous materials
  aggregate washwater and screenings

pesticides.

Wastes should be transported in vehicles designed to prevent spillage. If odors are a problem, the vehicle should be entirely closed (the exterior of vehicles should be kept clean to prevent odor problems). The contractor could be required to maintain a vehicle cleaning station, with steam or high pressure water available. Overloading of vehicles is certain to result in spillage.

Vegetative debris may be landfilled, chipped and spread on bare earth, or burned in a pit incinerator or refuse incinerator, depending on state and local regulations. Wood chippings can often be stored and used later as a mulch on newly seeded areas or to protect bare slopes. Stumps or other organic material should not be buried where construction is expected in the near future, because the surface will settle as the material decays. In burying waste, leachate problems, groundwater pollution, and future settlement must be considered. Land disposal of problem material, such as organic overburden and muck, requires adequate compaction and covering with suitable soil.

The two basic principles in designing against landfill leachate pollution are: prevent water from entering the landfill, and prevent leachate from reaching the groundwater. Methods commonly used to prevent water from entering the landfill include: (a) intercept all runoff and bypass it around the area, and (b) place an impervious soil, or membrane, cover over the landfill and adequately slope and drain the surfaces of the landfill to prevent water from ponding. Construction techniques commonly used to prevent leachate from reaching the groundwater include preparation of the site by: (a) underlining the entire site with an impervious clay layer or a membrane and/or placing a systems of drains and/or gravel adequately sloped to drain leachate to a sump where it can be pumped to a treatment facility; and/or (b) designing the low point of the landfill no less than 4 ft above the water table. The landfill material should be baled before placing, or maximum compaction obtained after placing, to minimize the rate of leachate formation, the decomposition of organic material, and the rate of percolation through the fill. For additional requirements, see reference *(3)*.

5.4 EXCAVATION AND BACKFILL

Excavation should be done with the least disturbance to ground cover and tree root systems. Excavated material should be stockpiled in such a way that it will not be a source of silt or pollution in stormwater runoff or be a source of dust in the air. Diking, chemical treatment, reseeding, and/or covering with tarpaulins may be desirable.

Excavation in stream, ocean, or lake bottoms should be controlled, to minimize damage to fish spawning areas and shellfish beds. For example, clamshell or orange peel buckets could be specified instead of dragline buckets. Blasting should be done according to accepted safety practices and should also be limited to daytime working hours when such noise is more acceptable. Excavations where the walls of the opening are not sufficiently supported can cause subsidence of adjacent land and damage to structures. Excavation and fill slopes of ponds and lagoons require protection against wave action as well as against erosion and must be amenable to efficient removal of scum, debris, or weed accumulation. Experts in soil mechanics and geology should assist in the design of the shoring or piling used to adequately support the walls of an excavation.

Subsidence of land and structures can be caused by lowering of the water table. Granular material is often placed on the bottom of excavations or trenches, to keep the working surface dry and to drain infiltrating groundwater or stormwater to a sump where the water is pumped out, thus possibly lowering the water table adjacent to the excavation. In other cases, well point systems are used to lower the water table below the excavation to keep the site dry. Adjacent soils should be examined by soils experts (if there is a question), to ensure that permanent drainage in areas where groundwater is near the surface is designed to prevent subsidence of the soil and possibly of structures resting on that soil. In older urban areas, structures may have been built on wooden piling which has been kept continuously wet by high groundwater. If the water table is lowered, the piling may become weakened, resulting in settlement damage to structures.

Material used for backfill must be carefully selected, and methods used for placement must be designed to ensure satisfactory compaction. Organic matter such as wood shoring or stumps must be removed from any backfill. The construction contractor should be required to return and repair, within 1 year, any surface irregularities or other damage caused by faulty excavation or faulty backfill.

5.5 PILE DRIVING, BLASTING, AND EARTHQUAKE PROBLEMS

Potential vibration or shock waves must be considered in the design of wastewater works, to protect them from earthquakes or to prevent damage to adjacent structures from construction procedures such as pile driving or blasting. All wastewater works must be designed to remain watertight and meet local building design regulations, including those relating to possible earthquakes. Pile drivers and explosives also cause noise and shock waves. The designer must specify construction methods, after consultation with competent geologists if necessary, which would minimize detrimental effects.

Selection of the correct type of piling or foundation support to meet site conditions (such as concrete poured into driven pipe or drilled holes) or of pile driving equipment (such as sonic pile drivers) can reduce or eliminate such problems, although at a higher construction cost.

All safety codes applicable to the use of explosives must be rigidly complied with, if damages are to be minimized. If pile driving or explosives must be used in a particular situation, the detrimental effects on the environment must be considered in the environmental assessment.

5.6 DREDGING

Before commencing dredging operations, the dredged material should be sampled to ascertain the proper method of disposal. Toxic or odorous substances in the dredged material will require special disposal techniques. Dikes around spoil and settling areas, overflow weirs, and outfall channels should be designed to prevent escape of dredged materials. Use of a clamshell bucket rather than a hydraulic dredge will decrease the water content of the dredged material and minimize the escape of silt in drainage from the spoil area. Also, bottom dump scows, which drop the spoil in a large mass, are preferred. Fish spawning areas and shellfish beds must be protected from siltation.

Dredging operations should be monitored for toxic substances and the escape of material from the spoil area. Contact the U.S. Army Corps of Engineers to determine permit requirements.

5.7 EROSION AND SILTATION

Erosion not only creates unsightly conditions but also leads to water pollution and muddy areas and is a source of dust. Inorganic silts in runoff water entering watercourses reduce the numbers and types of organisms normally present in the receiving stream. Silt can blanket the bottom, screen out light, change heat radiation, destroy living spaces, and create unfavorable conditions by covering organic materials. Silt may smother fish eggs, shellfish, and other bottom organisms and may interfere with fish feeding. Information on erosion and sediment control is contained in EPA guidelines *(5)*.

General recommendatons for sediment control on wastewater facility sites include *(7)(11)*:

> Plan development to fit drainage patterns, topography, and soils of the construction site.
>
> Avoid removal of trees and surface vegetation wherever feasible.
>
> Minimize exposed land area and duration of exposure.
>
> Divert runoff around exposed areas to stabilized outlets.
>
> Provide temporary cover on areas of critical erosion hazards, and establish permanent cover as soon as possible.
>
> Construct impoundments to trap sediment and reduce runoff peaks before flow leaves the construction area.

Meyer *(6)* describes a method for predicting soil loss from erosion. The amount of erosion is determined in large measure by soil type, degree of slope, and shape of the transition at the top and bottom of the slope.

Fording of streams, another source of erosion, should be carried out by bridging the streams, sheeting, using conveying equipment, or constructing a stabilized roadbed into and through fords.

Borrow pit operations should be controlled to prevent escape of sediments. The excavated area should be restored by proper grading, replacement of topsoil and vegetation, and revetment of steeper slopes. Revegetation *(7)(8)* is one of the best erosion control measures available. Vegetation selected must, of course, be hardy for the specific site. Mulch *(8)(9)* may be used to control runoff from bare slopes after seeding until the grass or other vegetation is well started or as a long term erosion preventive. Netting may be required over mulch. A mulch of wood chips or crushed stone is sometimes used as a permanent slope control against erosion. Burlap or plastic is sometimes used in place of mulch as a temporary measure.

Suggested procedures to improve chances of revegetation include:

Spoil areas should be graded. If revegetation must be delayed, areas should be temporarily covered with tarpaulins, burlap, or mulch.

Dikes or ditches to control runoff may be required.

Several inches of the original or imported topsoil over scalped soil is usually necessary, if seeding is to be effective.

Development of adequate soil fertility, which denuded soils often do not have, is essential. Irrigation with treated wastewater often provides sufficient nutrients tor good growth of vegetation, and conditioned disinfected sludge is a good soil conditioner.

Shallow tillage of areas immediately prior to seeding will break the crust, aid revegetation, and improve infiltration.

A seed mixture containing both slow and fast growing varieties proved satisfactory for the site conditions is desirable. Fast growng temporary varieties (such as rye) will protect slower growing permanent varieties (such as blue grass or fescue).

Mulching of seeded or planted areas is most important for speeding revegetation of denuded land.

Supplemental controlled irrigation is often required until growth is well underway.

Temporary erosion or runoff control measures such as impoundments, dikes, or ditches should be coordinated with the final project design. These temporary measures should be planned to minimize the additional earthwork necessary for final design.

Prior to the start of work, construction specifications should require that the contractor submit to the owner, for review and approval, proposed plans for clearing, excavating, grading, and constructing haul roads and borrow pits. Also needed are a plan for disposal of waste materials, for erosion control methods, for drainage during construction, and a land restoration schedule.

Wischmeier *(10)* describes an erodibility model using parameters obtained from routine laboratory determinations and standard soil profile descriptions. A nomograph is also presented. The parameters used are: percentage silt plus very fine sand, percentage sand greater than 0.10 millimeter, organic matter content, structure, and permeability. Wischmeier indicates that this technique can be used to plan sediment control measures such as determining the proper depth of cut to avoid highly erodible soil layers and the proper shape of the slope.

Erosion and runoff control measures are well known *(7, 11, 12, 13, 14)*. In summary, the following methods for erosion or runoff control are recommended for consideration:

Bare slopes should receive cross-slope scarification prior to mulching and revegetation. Contour plowing and/or terracing may also be effective for some plantings.

Slope shaping *(7)(10)* is an erosion control technique to reduce erosion rates and sediment yields. A concave slope will yield less sediment, because the steepest part of the slope occurs where flow is least. If a concave slope is not practical, a complex slope (convex upper and concave lower) will reduce sediment yield.

Permanent mulching, crushed rock, paving, or revegetation can be used to protect raw slopes.

Interceptor dikes and diversions using soil ridges or furrows may be constructed to carry runoff around the slope. Consideration should be given to revetting or lining such dikes or ditches (or providing check dams), if the ditches are expected to be permanent.

Waterways may be sodded or lined with gravel, stone, concrete, or asphalt.

Sediment traps made of hay bales or brush with wire fencing can be placed in steep natural channels to form a series of check dams.

In some cases, underground conduits are best for carrying trapped runoff from the site.

Before dredging operations which might lead to problems with runoff from the disposal area are begun, the dredged material should be sampled to ascertain the proper method of disposal. Toxic or odorous substances in the dredged material will require special disposal techniques. Approval for method of disposal of dredged material is to be obtained from the pertinent EPA regional administrator on a case-by-case basis.

Care should be taken during design and construction to minimize the amount of restoration work required.

Clearing and grubbing should be used in lieu of herbicides, if it is necessary to remove vegetation. Good drainage should be maintained on the site to eliminate stagnant pools, rather than using insecticides to prevent breeding of insects. Care must be taken not to significantly damage important ecological systems by faulty use of pesticides, if it is deemed necessary to use pesticides.

5.8 RESTORATION OF EASEMENTS AFTER CONSTRUCTION

To minimize costs of restoration of easements, measures to be taken during construction must be included in the specifications. It is often possible during restoration of easements and rights-of-way to improve the utility and attractiveness of a site, compared with its condition before construction, at little if any increase in cost. This is particularly advisable for property which has been adversely affected during construction.

Proposed changes in the restoration of easements to other than the original condition must be shown on the construction plans and be approved by the owner of the property on which the easement is located. Vegetation which will be hardy under conditions existing at the restored site, and which will permit quick and easy access for maintenance of the wastewater works, should be placed according to good landscaping principles.

Subjects which should be considered for inclusion in the construction specifications include:

normal excavation backfilling

allowable trench widths

allowable working widths

rock and boulder excavation

pumping and drainage

storage of excavated material

compaction procedure

boulder and stone fill

tree protection

disposal of rock and waste excavated material

trench surface restoration

recommendations of agricultural agent

topsoil

fertilizer and soil conditioners

reseeding and revegetation

mulching

riprap and other protective surfacings.

5.9 WASTEWATER TREATMENT DURING TREATMENT PLANT MODIFICATION

All new works and expansions to existing works must be designed for further expansion *(1)*. During a works upgrading or expansion, the interruption of normal operation must be minimized and will be subject to the approval of the EPA regional administrator *(1)*. If existing effluent quality must be maintained, it may be necessary to provide temporary treatment. Details on process design for temporary treatment works, if required, should be included in contract drawings and specifications. Contract documents should include provision for operation and maintenance of such temporary works.

Maintaining existing treatment levels during all periods of construction may not be feasible. Design standards for temporary facilities may be developed after the effect of effluent on stream water quality is determined. The importance of any detrimental effects to the environment must be evaluated before temporary works are designed. Losses to shell fishermen *(22)*, because of reduced disinfection efficiency, can be estimated. Loss of commercial fishing and loss of man-days of recreational fishing can be estimated from decline in DO (determined from accepted dissolved oxygen sag computations). Loss of swimming and boating time can be determined by relating effects of the effluent against appropriate water quality standards. Should water quality standards be violated, loss of swimming and boating will result. Loss of the value of recreation man-days can be balanced against cost of disinfection, color removal, turbidity removal, etc. Effluent standards, for use in the design and operation of any temporary treatment works, must be approved by the EPA regional administrator.

Disinfection of effluent is required to eliminate pathogens. High rate sedimentation may be carried out using coagulants in the remaining settling tanks while some tanks are out of service because of construction, or temporary settling basins may be constructed. Sludge handling might involve pumping to existing sludge facilities or holding in a temporary storage pit dosed with appropriate chemicals. Temporary tanks could be earthen berms with plastic liners. Multiple independent tanks may be needed to permit taking a tank out of service for sludge removal.

Temporary chemical treatment often involves high operating cost for chemicals; however, the capital cost of mixing equipment will be low. Lime, alum, and ferric chloride may be used as coagulants, but the cost of materials handling and the increased sludge volumes often make polymers a better alternative. A cost analysis of the two approaches is required.

Microscreens or high rate screens may be used in lieu of, or to augment, clarifiers. Physical treatment, including activated carbon, may be used to remove soluble organic material.

Holding and stabilization ponds may be constructed of earthen berms with plastic liners. Generally, temporary stabilization pond treatment may include: (a) aeration followed by disinfection of effluent, (b) aeration with the addition of chemical coagulants followed by settling and disinfection, or (c) facultative ponds followed by slow sand filters and disinfection.

It may be advantageous to use equipment intended for final construction during the temporary treatment phase. For example, chlorinators and mechanical aerators might be used for temporary treatment prior to final installation. Existing treatment processes might be converted for temporary treatment. For example, primary tanks might be used as aeration basins by adding floating mechanical aerators.

Package plants which will satisfy local requirements could be used for temporary treatment but require careful operation to obtain desired effluent quality.

The lack of process flexibility makes it desirable to monitor the temporary process, to avoid upset and loss of efficiency. Because of the lack of flexibility and the need for rapid assessment of treatment efficiency, the chemical oxygen demand (COD) or total organic carbon (TOC) test is preferred to the BOD test. The TOC test can be performed rapidly and can be automated.

5.10 SLUDGE, PROCESS SIDESTREAMS, AND ONSITE DISPOSAL

Inadequately treated or raw sludge is invariably a source of odor. Guidelines for the treatment of sludge and resulting process sidestreams are presented in the EPA technology transfer publication *Sludge Treatment and Disposal (15).* Process design information is provided in an EPA technology transfer process design manual on sludge treatment and disposal *(21).* Liquid sidestreams resulting from thickening, dewatering, or other sludge treatment processes are often potential sources of odor or require special treatment before being returned to the normal wastewater treatment flow, to prevent reduction in treatment efficiency. The final disposal of sludge is another major problem, because of possible runoff and groundwater pollution, damage to agricultural soils, and air pollution. Waste solids may be transported from the treatment facility to the disposal area as primary or secondary sludge (digested or not), sludge incinerator ash, or residue from heat treatment or wet air oxidation processes. Sludge may be piped, trucked, barged, or shipped by rail *(4, 17, 18).* Shipping sludge by rail may be feasible. Chicago has used a train to haul sludge from the city to outlying areas *(18)(19).* Pipeline transport eliminates the odor problem along the route and, if economically feasible, offers an alternative to truck haul of raw or digested sludge or filter cake. However, a pipeline system often requires a storage lagoon at the disposal site, and open lagoons are themselves a potential source of odor.

Truck haul of waste solids is common. Generally, residue from sludge incineration and wet air oxidation processes does not generate objectionable odor. Blowing dry ash may cause a problem; these loads should be dampened or covered. Methods and equipment to prevent spillage and drainage from trucks hauling liquid sludge should be provided.

Thickened, conditioned, or dewatered sludge cake may be a source of odors. If it is necessary to haul the cake through populated areas, the truck body should have airtight closure. Truck bodies used for hauling both sludge ash and filter cake should have a one-piece, pan-type body to prevent leakage, because gasket fittings cannot be relied on to remain tight. Tank trucks and portable liquid transport containers may be used to haul raw digested sludge.

Sludge loading areas should be designed to contain odors, by enclosing sludge handling equipment such as conveyor systems. Such equipment must still be accessible for lubrication, cleaning, and general maintenance.

Discharge of sludge from the treated sludge hopper to the vehicle should be through an enclosed flexible chute. Tank cars may be loaded using pressure fittings, venting the empty tank to an odor disposal unit. Loading sites should be designed to eliminate areas where sludge can collect and should have high pressure water hose or steam cleaning apparatus available.

Frequent cleaning of equipment is essential. Overloading, with consequent spillage, should be avoided. Adequate standby vehicles and equipment should be provided.

Before discharge to treatment processes, if it is difficult to control the formation of aerosols, disinfection should be provided if there is a possibility that the aerosols or their residues will come in contact with humans. State and federal regulations regarding disinfection of wastewater and sludge must be followed and standby equipment provided for emergencies, if significant danger to the health of others might result from failure of the initial disinfection process.

Some chlorinated organics in low concentrations are toxic to aquatic biota and humans. This must be considered in selecting the disinfection method and/or agent to be used.

Consideration should be given to the possibility of hazardous conditions which might arise if the containers used to transport gaseous disinfecting agents were damaged during transportation or use.

Consideration must be given to disinfection of treated wastewaters which will be used for spray irrigation, particularly if there is any possibility that runoff can carry pollutants or pathogens from the site to neighboring land or public bodies of water. Disposal of undisinfected wastewater or sludge on site is a potential danger to wastewater works operation and maintenance personnel who must walk through the irrigated areas to perform their work. Special boots and protective clothing should be made available for workers who must enter or work in such areas.

5.11 GROUNDWATER POLLUTION

Groundwater is a very valuable resource—once contaminated, it is very slow to recover. Because of the many unknowns, design measures to protect groundwater must be conservative. If there is any chance of groundwater pollution, a soils testing program should be established, monitor wells should be installed, and a regular water sampling and testing program should be instituted. Groundwater must be adequately protected from any degradation in use or pollution. If inadequately treated wastewater or sludge is placed on or in the soil, there is a possibility of groundwater pollution.

Wastewater pipelines or structures can be dangerous sources of pollution, if adequate provisions are not made by the designer to ensure that such pipelines or structures will be reasonably leakproof. Granular bedding under structure foundations or pipes can also act as a drain and carry wastewater leakage into aquifer recharge areas.

Investigation of soils and aquifers along rights-of-way should be conducted, so that the pipeline and foundations can be designed to prevent wastewater leakage into aquifers. Care must be taken in designing land application operations and plant operation and maintenance procedures, to ensure that dangerous amounts of pollutants such as nitrogen, sodium, heavy metals, pesticides, or pathogens will not be carried into the groundwater by surface water percolating through the soil. In general, the control methods are similar to those used to prevent landfill leachate pollution of groundwater described in section 5.3. Other control methods include disinfection and/or special treatment before land application. The Environmental Protection Agency has developed standards to protect groundwater used for raw source drinking water supply *(23)*. All land application operations must insure that these standards are maintained.

Other adverse effects may result if nutrients or pollutants are adsorbed temporarily on fine grained soil particles and later released to the groundwater. The adsorptive capacity of some soils for some heavy metals and organic compounds is small, and after this capacity is reached such soils no longer remove these pollutants from the water.

Procedures are set forth in references *(20)(21)* to assist in evaluating systems for land application of treated municipal wastewater. Reference *(21)* contains an evaluation checklist and is concerned with facilities plans, design plans and specifications, and operation and maintenance manuals for land application systems.

5.12 REFERENCES

1. *Design Criteria for Mechanical, Electric, and Fluid System and Component Reliability*, EPA-430-99-74-001 (1973).
2. *United States Water Resources Council—Flood Hazard Evaluation Guidelines for Federal Executive Agencies*, Washington, D.C. (1972).
3. *Sanitary Landfill Guidelines*, EPA (6 April 1972).
4. MacKenthun, Kenneth M., *The Practice of Water Pollution Biology*, Division of Technical Support, Federal Water Pollution Control Administration, U.S. Department of the Interior, U.S. Government Printing Office, Washington, D.C. (1969).
5. U.S. Environmental Protection Agency, *Guidelines for Erosion and Sediment Control Planning and Implementation*, EPA-R2-72-015, U.S. Government Printing Office, Washington, D.C. (August 1972).
6. Meyer, L. Donald and Kramer, Larry A., "Erosion Equations Predict Land Slope Development," *Agricultural Engineering*, Vol. 50, No. 9 (September 1969).
7. Meyer, L. D., *Reducing Sediment Pollution by Erosion Control on Construction Sites*, Paper Presented at Seventh American Water Resources Conference, Washington, D.C. (October 1971).
8. Meyer, L. D., *et al.*, "Erosion Runoff and Revegetation of Denuded Construction Sites," *Transactions of the American Society of Agricultural Engineers*, Vol. 14, No. 1, St. Joseph, Michigan (1971).
9. Meyer, L. D., *et al.*, "Mulch Rates for Erosion Control on Steep Slopes," *Soil Science Society of America Proceedings*, Vol. 34, No. 6, Madison, Wisconsin (November/December 1970).
10. Wischmeier, W. H., *et al.*, "A Soil Erodibility Nomograph for Farmland and Construction Sites," *Journal of Soil and Water Conservation* (September/October 1971).
11. Environmental Protection Agency, Office of Water Program Operations, *Control of Erosion and Sediment Deposition From Construction of Highways and Land Development*, U.S. Government Printing Office, Washington, D.C. (1971).

12. U.S. Department of the Interior, Federal Water Quality Administration, *Urban Soil Erosion and Sediment Control*, U.S. Government Printing Office, Washington, D.C. (1970).

13. Lotspeich, Frederick B., *Environmental Guidelines for Road Construction in Alaska*, Environmental Protection Agency, Alaska Water Laboratory, College, Alaska, No. 1610, G01 08/71 (August 1971).

14. Dalton, F. E., *et al.*, "Land Reclamation—A Complete Solution to the Sludge and Solids Disposal Problems," *Journal WPCF*, Vol. 40, No. 5 (May 1968).

15. U.S. Environmental Protection Agency, Technology Transfer, *Process Design Manual for Sludge Treatment and Disposal*, (October, 1974).

16. Taynes, Bertram C., "Economic Transport of Digested Sludge Slurries," *Journal WPCF*, Vol. 42, No. 7 (July 1970).

17. Sparr, Anton E., "Pumping Sludge Long Distances," *Journal WPCF*, Vol. 43, No. 10 (October 1971).

18. Triebel, W., "Experiences With the Disposal of Sewage Sludge in Agriculture," *Korresp. Awass.*, No. 10 (1966).

19. Freytag, B., "Hygienic Aspects of the Utilization of Sewage and Sewage Sludge in Agriculture," *Sehr Reihe Kuratoriums Kulturbaum*, No. 16 (1967).

20. Pound, C.E., and Crites, R.W., *Wastewater Treatment and Reuse by Land Application—Volume II*, U.S. EPA Office of Research and Development, EPA-660/2-73-0066 (August 1973).

21. *Evaluation of Land Application Systems*, EPA-430/9-75-001 (1975).

22. U.S. Environmental Protection Agency, Office of Water Program Operations, *Protection of Shellfish Waters* (July, 1974).

23. *National Interim Primary Drinking Water Regulations*, (40 CFR 141, Federal Register, Dec. 23, 1975).

APPENDIX A: Reference Legislation

FEDERAL LAWS AND EXECUTIVE ORDERS WHICH AFFECT THE CONSTRUCTION GRANTS PROCESS AS ADMINISTERED BY THE ENVIRONMENTAL PROTECTION AGENCY

I. LAWS AND ORDERS OF MAJOR DIRECT SIGNIFICANCE

A. Environmental Impact

1. The Archaeological and Historic Preservation Act of 1974 (16 U.S.C. 469a-1 et seq.);

2. The Clean Air Act (42 U.S.C. 1857b-1 et seq.);

3. The Coastal Zone Management Act of 1972 (16 U.S.C. 1451 et seq.);

4. The Endangered Species Act of 1973 (16 U.S.C. 1531 et seq.);

5. The Federal Water Pollution Control Act, as amended (33 U.S.C. 1251 et seq.);

6. The Fish and Wildlife Coordination Act of 1958 (16 U.S.C. 661 et seq.);

7. The Flood Disaster Protection Act of 1973 (12 U.S.C. 24.1709-1, 42 U.S.C. 4001 et seq.);

8. The Marine Protection Research and Sanctuaries Act of 1972 (16 U.S.C. 1431 et seq. 33 U.S.C. 1401 et seq.);

9. The National Environmental Policy Act of 1969 (42 U.S.C. 4231 et seq.);

10. The National Historic Preservation Act of 1966 (16 U.S.C. 470 et seq.); Executive Order 11593 ("Protection and Enhancement of the Cultural Environment," May 13, 1971); and 36 CFR Part 800 ("Procedures For the Protection of Historic and Cultural Property, January 25, 1974);

11. The Rivers and Harbors Act of 1899 (33 U.S.C. 401 et seq.) particularly 403 requiring Corps of Engineers permit for dredge and fill activity);

12. The Safe Drinking Water Act of 1974 (16 U.S.C. 1424e);

13. The Solid Waste Disposal Act (42 U.S.C. 3259);

14. The Water Resources Planning Act of 1965 (42 U.S.C. 1962d), all as amended;

15. The Wild and Scenic Rivers Act of 1968 (16 U.S.C. 1274 et seq.);

16. Executive Order 11296 ("Evaluation of Flood Hazard in Locating Federally Owned or Financed Buildings, Roads, and Other Facilities, and in Disposing of Federal Lands and Properties," August 10, 1966);

17. Federal Insecticide, Fungicide, and Rodenticide Act as amended (7 U.S.C. 136 et seq.);

18. The Noise Control Act of 1972 (42 U.S.C. 4901 et seq., 49 U.S.C. 1431);

19. Administrator Decision Statement #4, "EPA Policy to Protect the Nation's Wetlands," February 21, 1973.

B. Other Impact

1. The Civil Rights Act of 1964 (particularly Title VI and excluding enforcement and compliance) (42 U.S.C. 2000e et seq.) and Executive Orders issued thereunder ;

2. The Davis-Bacon Act (excluding enforcement and compliance) (40 U.S.C. 276a);

3. The Intergovernmental Cooperation Act of 1968 (40 U.S.C. 531 et seq., 42 U.S.C. 4201 et seq.);

4. The Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970 (42 U.S.C. 1415, 2473, 3307, 4601 et seq., 49 U.S.C. 1606);

5. Executive Order 11246, with regard to equal employment opportunities;

6. The Contract Work Hours and Safety Standards Act (40 U.S.C. 327 et seq.);

7. The Copeland (Anti-Kickback Act) (40 U.S.C. 276b, 41 U.S.C. 51 et seq.);

8. The Hatch Act (5 U.S.C. 1501 et seq.);

9. Executive Order 11738, prohibiting utilization of facilities on EPA List of Violating Facilities.

II. ACTS WHICH PROVIDE ADDITIONAL FUNDING

1. Appalachian Regional Development Act (Allows matching of EPA grants with ARC funds);

2. Consolidated Farm and Rural Development Act (Makes grants and loans available from the Farmers Home Administration for small towns to raise funds for their matching share of EPA assisted projects);

3. The Demonstration Cities and Metropolitan Development Act and Intergovernmental Cooperation Act of 1966 (42 U.S.C. 3311, 3374);

4. Housing and Urban Development Act of 1974 (Community development block grants may be used to match EPA's 75% grant, but only for collector and interceptor sewers);

5. Public Works and Economic Development Act of 1965, as amended (Allows Economic Development Administration to match EPA grants).

★U.S. Government Printing Office: 1976-678-234/329 Region 8